FORESTRY

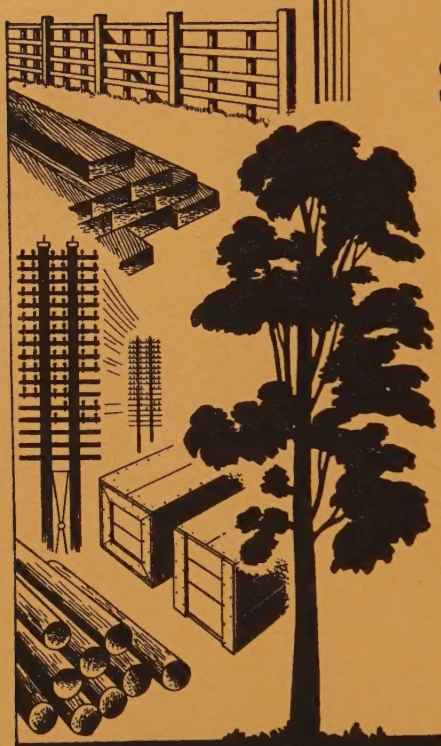
THE JOURNAL OF THE SOCIETY OF FORESTERS OF GREAT BRITAIN

Edited by H. M. STEVEN

VOLUME XVI

Price
Fifteen Shillings

Published by the
OXFORD UNIVERSITY PRESS
LONDON: HUMPHREY MILFORD
AMEN HOUSE, E.C. 4
Temporary address:
SOUTHFIELD HOUSE, HILL TOP ROAD
OXFORD
1942



LUMBERMEN
and
SAWMILLERS

with over a century of service.

- TELEGRAPH POLES, PIT PROPS, COLLIERY TIMBERS, RAILWAY SLEEPERS, PACKING CASES, BOXWOOD, ESTATE, FARM, & GARDEN FENCING

Estd. 1824

A & G. Paterson

LIMITED

ST. ROLLOX SAWMILLS & BOXWORKS

60-80 Tennant St. Glasgow C 4

TELEPHONE: BELL 3236 (3 lines)

Permanent Sawmills at Banchory & Aberdeen

FOREST SAWMILLS THROUGHOUT THE COUNTRY

FORESTRY

THE JOURNAL OF THE SOCIETY OF FORESTERS OF GREAT BRITAIN

Edited by H. M. STEVEN

VOLUME XVI

Published by the
OXFORD UNIVERSITY PRESS
LONDON : HUMPHREY MILFORD
AMEN HOUSE, E.C. 4
Temporary address:
SOUTHFIELD HOUSE, HILL TOP ROAD, OXFORD
1942

FORESTRY

CONTENTS OF VOLUME XVI

Some Ecological Aspects of Afforestation and Forestry in Great Britain (with Plates I–IX). By SIR ROY ROBINSON 1

Investigation on the Rate of Drying of Pit-props. By W. H. GUILLEBAUD . 13

Anisotropic Contraction of Wood and of its Constituent Cells. By R. D. PRESTON 32

The Variability in Resistance to Decay of the Heartwood of Home-grown European Larch, *Larix decidua*, Mill. (*L. europaea*) and its Relation to Position in the Log. By K. ST. G. CARTWRIGHT 49

The Number of Sample Trees required for determining Volumes of Woods with Various Degrees of Accuracy. By REGINALD DAVEY . . . 52

Society's and Other News 56

REVIEWS

Measurement of Trees (REGINALD DAVEY). By JAMES MACDONALD . . 56

The English Woodland (JOHN ROGERS). By W. L. TAYLOR . . . 58

Forest Tree Seed (HENRY IVES BALDWIN). By H. M. STEVEN . . . 59

EDITOR'S NOTE

THE Council has decided for reasons of economy in paper, &c., that *Forestry*, Volume XVI, 1942, shall consist of one Number only.

PRINTED IN GREAT BRITAIN

SOCIETY OF FORESTERS OF GREAT BRITAIN

THIS SOCIETY was formed in 1925 and adopted its first Constitution at Oxford in 1926. The object of the Society is to advance and spread in Great Britain the knowledge of technical forestry in all its aspects.

The Society consists of Professional and Ordinary Members. Professional membership is divided into two orders:

FELLOWS, being holders of a degree or diploma in forestry, and subjects of the British Crown, but not necessarily resident in Great Britain; and

ASSOCIATES, being subjects of the British Crown resident in Great Britain, whole-time foresters, and not eligible for Fellowship. They pay a less subscription than Fellows but have almost equal privileges.

Ordinary membership is open to persons not eligible for either of the above.

Office-bearers and Councillors are nominated by Professional Members, and in the event of competition for any office a postal ballot of the whole Professional membership is held. The following were elected to serve in 1940:

President: WHEATLEY A. ROBERTSON, F.R.G.S., Director of Forest Products Research, Princes Risborough.

Vice-President: W. H. GUILLEBAUD, B.A., Chief Research Officer, Forestry Commission.

Editor of Journal: PROFESSOR H. M. STEVEN, M.A., PH.D., 75 Fountainhall Road, Aberdeen.

Business Editor: J. ALAN B. MACDONALD, 25 Drumsheugh Gardens, Edinburgh, 3.

Secretary and Treasurer: R. ANGUS GALLOWAY, M.C., B.SC., Solicitor, 8 Rutland Square, Edinburgh, 1.

Auditor: D. L. FERGUSON, 25 Drumsheugh Gardens, Edinburgh, 3.

Councillors: W. L. TAYLOR, F.S.I., Forestry Commissioner, London (Immediate Past President).

A. H. GOSLING, B.SC.

T. R. PEACE, M.A.

OWEN J. SANGAR, M.C.

C. A. CONNELL, M.A.

E. V. LAING, M.A., D.SC.

C. H. THOMPSON, M.A., DIP. FOR.

THE SOCIETY AND ITS JOURNAL

THE IMPORTANCE OF FORESTRY is being realized more and more in Great Britain. The number of foresters is increasing steadily, and a forestry profession is gradually being built up. It is intended that this Society should be representative of the profession. Those who are not engaged in the practice of forestry or the allied sciences are cordially invited to join the Society as Ordinary Members.

SUBSCRIPTIONS are:

Fellows and Ordinary Members: £1. 1*s*. 0*d*. annually or £10. 10*s*. 0*d*. for Life.

Associates: 10*s*. 6*d*. annually.

THE SOCIETY'S JOURNAL, called *Forestry*, is published twice a year, in June and December. It provides a means for the publication of the results of practice and research both in the growing of timber and in its utilization, including such basic sciences as forest physiology and ecology, forest soils, wood structure, and timber physics, and allied sciences such as forest entomology and forest mycology.

CONTRIBUTIONS may be accepted from members and others resident either in Great Britain or abroad. They should be sent to the editor, Professor H. M. Steven, 75 Fountainhall Road, Aberdeen. No article should be submitted which is being offered to any other journal for prior or simultaneous publication. Articles should be typewritten, and must be in a final form suitable for publication. References to literature should be collected at the end of the paper, and arranged alphabetically according to author's name, and numbered. In the text each reference should be indicated by its number enclosed in brackets. Each article should conclude with a summary. It should give the methods, extent of material, observations, and results, but should be brief and not exceed 3 per cent. of the original. It is understood that the author waives any copyright or translation rights in such summaries and that their reproduction in other publications will be permitted, subject to the source being duly acknowledged. Twenty reprints of the article will be sent free to each contributor and a reasonable number may be purchased by the contributor if ordered when the proofs are returned. The Society as a body takes no responsibility for the views expressed by contributors.

Forestry is sent free to members of the Society; others may register as subscribers by application to the Secretary, R. Angus Galloway, 8 Rutland Square, Edinburgh, 1.

SOCIETY'S MEDAL. The Council has resolved that the Society award a Medal from time to time to any individuals who may have rendered eminent services.

SOME ECOLOGICAL ASPECTS OF AFFORESTATION AND FORESTRY IN GREAT BRITAIN

BY SIR ROY ROBINSON

INTRODUCTION.

ECOLOGY plays, or should play, an important part in forestry. The man who distributes his tree species on an afforestation area according to the types of existing vegetation is consciously or unconsciously applying his knowledge of ecology and promoting an artificial succession of vegetation which his experience leads him to think will flourish.

The object of this article is twofold: first to record the steps by which I have personally and in gradual stages come to a further appreciation of the silvicultural significance of ecological studies, and, secondly, to propound two working hypotheses which may perhaps further ecological research and also prove of direct utility to foresters.

My attention was first attracted to the importance of the subject about 1912, when the experimental afforestation areas established by the Office of Woods and Forests were placed under my technical direction. These areas included the Isle of Man Plantations (dating from 1883), Hafod Fawr (1900), and Inverliever (1909). In all of them more or less difficult ground had been planted with poor results. It was important to get to the bottom of these failures, and there was begun then a long series of investigations which have been carried on since 1919 by the Research Branch of the Forestry Commission and have led up to the present technique in afforesting difficult sites.

Investigations have not been confined to the State forests; indeed, the best and most inspiring example of the afforestation of difficult sites is that of Sir John Stirling Maxwell at Corrour where original and patient experiments over some 50 years have yielded outstanding results.

It was soon obvious that a rough correlation existed between the existing surface vegetation and the successful growth of tree species. Acting under my instructions that excellent forester, the late John Boyd, worked on the problem in 1913–14 and produced for Inverliever a correlation table of vegetation and tree species which, for a first effort, has stood up well to the test of time.

The assumption that the type of vegetation was as good as any other single guide to the plantability of ground and the choice of species has strengthened as time went on, and such descriptions as 'bracken ground', 'molinia ground', and 'heather ground', to take three common examples, convey at once to the foresters' mind strong impressions of the possibilities and difficulties of afforestation. In all the reports on the acquisition of land for the Forestry Commission emphasis has, therefore, been laid on the character of the existing vegetation.

In its studies of tree growth and in its numerous planting experiments the Research Branch has investigated vegetation types and soils and has gradually

thrown a great deal of light on the whole complex question. Reference is made at a later stage to some of these experiments. On the more general question attention is drawn to two interesting articles by Steven (10, 11).

TWO WORKING HYPOTHESES.

It will be convenient first to set out the two working hypotheses which are here propounded as the result of more recent observations, and subsequently to record the facts and arguments on which they are based. The hypotheses are as follows:

1. ACCELERATED SUCCESSION. *In the natural afforestation of difficult sites some species are pioneers and some are successors. It is not feasible by artificial means to bring in the successors in advance of the pioneers. It is possible, however, to accelerate the natural succession by mixed planting of pioneers and successors and by appropriate thinning treatment to complete the succession in the course of a single rotation. A successor on one site may be a pioneer on another.*
2. THE SILVICULTURAL STREAM. *In the silvicultural treatment of woodlands the most effective methods are those which proceed in the direction of a natural succession of vegetation.*

Accelerated Succession

The first hypothesis refers specifically to 'difficult sites', and some explanation will first be given of what the term means in Britain. The bulk of the land which is available for afforestation has been grazed or periodically burned for long periods of time and in those processes has been greatly reduced in fertility, sometimes practically to bedrock. A good account of the effect of long-continued heather burning and grazing upon the moorland vegetation of the west of Scotland is given by Fraser (1). Perhaps the most striking change brought about by inclosure and cessation of burning in hill country is the great development of heather (*Calluna vulgaris*). Often the heather to begin with is so inconspicuous that it passes unnoticed, but land which was apparently green and grassy may quickly assume the appearance of a heather moor. It is such areas as well as those which originally were easily recognizable as heather moors which have given so much trouble in afforestation.

Another type which has given trouble is the bare chalk downland, well grassed but occasionally showing signs of the ubiquitous heather.

There are other types of difficult sites, such as the deep peats, but the two extremes, namely, the acid soils of the older rocks and the lime soils of the chalk, will serve as sources from which to draw examples on which the hypothesis of accelerated succession is based.

Mixtures of Pines with other Species. The following examples of the development of various species in mixture with pines are examples of the field observations on which the first hypothesis is based.

In Swaffham Forest C. 47[1] was planted in P. 26[1] completely with Douglas fir, which appeared to show a 100 per cent. death at the end of the growing season. In P. 27 the area was beaten up 100 per cent. with Scots pine which grew satis-

[1] The abbreviation C. means Compartment, P. the year of planting.

factorily and at the normal rate for the next 4 years. During this time there was no sign of any Douglas fir amongst the crop. By 1932 there was evidence everywhere that Douglas fir were coming away, and by 1935 there was no doubt at all that they were going to take a part in the crop.

Since 1935 this compartment has been kept under close watch, and it has been very interesting to note the gradual change from Scots pine with small Douglas fir through Scots pine and Douglas fir mixture to Douglas fir with Scots pine. In many parts the Scots pine have been completely suppressed, leaving a very promising plantation of pure Douglas fir, as yet rather uneven in height growth but with adequate, strong, and well-formed stems to make a final crop. This plantation is illustrated in Plate I.

In the New Forest just after the last war considerable areas of felled pine plantations on sandy heath or on heavy clay were replanted with Douglas fir, Sitka spruce, and Norway spruce. Invariably where heather developed the plants went into check and remained so until the ground had been re-seeded naturally from adjacent pine. Then in each case the phenomenon which occurred in the Swaffham area with Douglas fir was repeated with Douglas fir, Sitka spruce, and Norway spruce. Examples are numerous in the New Forest, but good instances are to be found in Vinney Ridge Inclosure, C. 2 and 6 (Douglas), Knightswood, C. 15 and 17 (Norway spruce), Furzey Lawn, C. 1, 3, and 4 (Norway and Sitka spruces), and other inclosures.

Passing from the low to the hill country, Scots pine/Norway spruce and occasionally Scots pine/Sitka spruce mixtures were planted at Coed-y-Brenin on heather ground usually in the proportion of 1 row pine to 2 rows spruce. Adjoining these mixtures are to be found pure spruce plantations on precisely similar ground. The contrast in growth between the growth of spruce when planted pure and when mixed with pine is very striking. Pure, the spruce are still in check 16 years after planting only a foot or two in height with yellow short needles. In the mixture they are of normal vigorous development and 10–12 feet high. Two photographs of C. 54, P. 26 (Plates II and III) illustrate this. Plate II shows vigorous Norway spruce on the right and characteristically rough Scots pine on the left. Plate III is specially interesting. It shows Scots pine on the left extending their influence for two to three rows into the pure spruce planting, and, on the right, checked spruce still in the heather.

Results similar to those at Coed-y-Brenin have been secured in Thornthwaite Forest, C. 95, P. 28. The vegetation is *Calluna*-grass on gravelly loam and the elevation 1,100 feet. Plates IV and V illustrate the plantation. The side branches of the pines have been pruned back to admit more light to the spruce.

These large-scale results are confirmed by a series of mixed plantings made by the Research Branch in experimental areas, Achnashellach (P. 28), Allerston (P. 28), and Teindland (P. 27 and 28) and elsewhere. In these the ground was deeply ploughed or otherwise worked, manures (basic slag) sometimes applied, sometimes not. Scots, Contorta, and Mountain pines have all been used in mixtures with Norway and Sitka spruces. In every case there has been a marked response, though the different pines vary in efficiency. Probably it will be found

that the order of usefulness is Scots and Corsican, Mountain, and lastly Contorta pines, though the status of Contorta is not yet definite. The photographs illustrate the present condition of some of the mixed plantations, and the following are worthy of close examination: at Allerston (Plate VI*a*) Exp. 6, P. 28, Scots pine and Sitka spruce on 3-furrow ploughing, no manure; Plate VI*b* showing the side effect of Corsican pine on Sitka spruce planted pure, manured, on 3-furrow ploughing; Plate VII*a* Sitka spruce pure on complete ploughing. This should be compared with Plate VI*a* of the mixed Scots pine/Sitka; Plate VIII*a* is of Teindland, Exp. 16, P. 27. It shows the vigorous growth of Sitka spruce in mixture with *Pinus contorta*. The soil is poor and sandy, and the density of the *Calluna* is obvious from the photograph.

As this inquiry has been pursued, some interesting facts about mixtures have been brought to light. For example, it has always been contended from the Commission's unhappy experience of planting Douglas fir in South Wales that the failures were due to industrial fumes. I have recently discovered, however, in Rheola Forest, C. 6, a Douglas fir/Scots pine mixture with a life-history almost identical to that of the Swaffham example quoted above. It was originally planted in P. 25 with Douglas fir which were abandoned as a failure and replanted in P. 32 with Scots pine. Both species are now 6–12 feet high (with a few backward Douglas fir still emerging from check); the Douglas fir are making leaders up to 20 inches in length.

Enough has been said to establish the fact that on typical *Calluna* sites mixed pine/spruce and pine/Douglas will grow vigorously, whereas pure crops of spruce and Douglas check almost indefinitely. There are also indications that *Tsuga heterophylla* behaves in a way similar to the spruces and Douglas, but further confirmation is required. One further interesting example may be added relating to a mixed Corsican pine/Douglas fir stand established on sand-dunes by the proprietor of Binsness adjoining Culbin Forest. The moving sands were fixed and immediately planted some 37 years ago. A sample plot was measured in 1936 and gives the following data: age 31 years, Corsican pine height 32 ft., mean diameter B.H. 5 in.; Douglas height 35 ft., diameter 5 in. vol. per acre; Corsican 820 cu. ft.; Douglas 1,100 cu. ft.; total 1,920 cu. ft. This is a site on which it would be quite hopeless to attempt to raise Douglas fir pure.

Norway Spruce in Mixture with Beech and Ash. Passing now to the other extreme of difficult sites, namely the open chalk downs, it can be stated that pure beech and pure ash plantations check almost as badly as do pure spruce on *Calluna* sites. Scots, Corsican, and Austrian pines, however, play the same part in bringing on beech on chalk as the pines do generally with spruces, &c., on heather. It seems probable, though difficult now to confirm, that many of the isolated clumps of beech on the Downs were raised in this way. C. 21, Gardner Forest, is an example, and there are others in the same neighbourhood.

Unexpectedly, also, Norway spruce will serve the same purpose as pine on chalk. Plate VIII*b* illustrates the results which can be obtained. Between the dark spruces right and left are a thin but vigorous ash (left) and vigorous beech (centre). The forest is Brighstone Down (Isle of Wight), C. 15, exposed directly to the

south-west winds, soil very thin over the white chalk. The plantation was made in P. 20 by a former proprietor and eaten back to ground level by rabbits. Properly protected since 1929, the broad-leaved trees have now attained in 12 years a height of 20 feet.

Subsequent Development of Mixtures of Pine, &c. The above are but a few examples of many which might be quoted to show the beneficial effect which a pioneer species (pine) has when planted simultaneously with or later than the successor species (Douglas fir, spruces, beech, and others). The plantations are now old enough to indicate that with this initial stimulus the successors will rapidly surpass the pioneer. There is also much evidence to show that the process continues to the end of the rotation. A good deal of mixed pine/Norway spruce planting, now semi-mature, has been done on private estates (for example in the south of Scotland), and although it is difficult at this stage to say whether the sites were typically heather, it is almost invariably the case that the spruce has taken the upper hand. One good example on a typical heather site was recently felled in Kerry Forest. The elevation is 1,550 feet, the soil compact sandy loam, the age 65. The volume per acre was 3,000 cu. ft., of which spruce accounted for about 75 per cent. of the contents. About 30 per cent. of the trees were pine, semi-suppressed, and of bad form. The spruce were free of butt-rot.

Interpretation of the Data. The suspicion that the data stated above might be capable of wider interpretation first arose in my mind on proceeding direct from the mixed plantations in New Forest to some experimental areas in Wareham Forest. In the latter, as part of the general scheme of experimentation and under soil conditions not markedly different from New Forest, the Research Branch had been attempting to raise spruces, Douglas, &c., in pure crops by soil cultivation and the application of basic slag. The trees showed an initial growth stimulus which soon died away, and it was apparent that vigorous crops were not to be secured in that way. It seemed that some essential stage was being omitted and the question arose: How would Nature, unaided, bring in a crop of those recalcitrant species? The answer was clear—not in a single step, but in a series of successions in which the desired species might not appear until quite a late stage.

To follow up this line of speculation, let us imagine that Nature has ready for distribution a supply of seed of the species which we may want to plant under any stated conditions.

On heather sites the first invading tree species would be those which were 'hardy' and possessed light seeds. Scots pine and birch are the two native species which present themselves most prominently, and among the exotics European and Japanese larches. We know that almost everywhere Scots pine will sow itself naturally on heather sites, though at high elevations and in damp positions it may not attain to better than scrub dimensions. What do we know about the succeeding vegetation under natural conditions? Not very much, because in Britain the species with which we are concerned are either too new to the country or have not been grown in circumstances under which they could seed themselves under Scots pine. We do know, however, that in historical times Norway spruce has gradually invaded the pine forests of Sweden from the south towards the

north. There are also examples of Douglas seeding freely in New Forest (Buscott's Inclosure, C.s 6B, 7A, 8B, and others) under 80-year-old Scots pine and developing in such a way as to suggest that they would ultimately oust the pine. Further, *Tsuga heterophylla* has been planted successfully through scrub pine at Teindland and elsewhere. Its growth has been rapid, and it is reasonable to suppose that it would soon surpass and suppress the pines. In all these cases, therefore, it would appear that there is a natural succession from the Scots pine forest on the one hand to the spruces, Douglas fir, or Tsuga forest on the other. In terms which, as will appear later, are over-simplified the pines would simply die of old age or suppression, and pine seedlings, being unable to survive under the dense shade of the spruce, Douglas fir, &c., would disappear from the site.

Birch is in some respects a disappointing pioneer species. It does not always make its appearance where it might be expected, and if planted on heather sites frequently refuses to grow. It is possible that some improvement in soil aeration is necessary; for instance, its growth is excellent on the deeply ploughed sandy heaths at Clipstone Forest. The fact that birch colonizes old woodland soils (both on heath and on chalk) suggests that lack of aeration is not the sole reason for non-success.

It is an easy matter, however, to complete the succession of birch woods to spruces, Douglas fir, Tsuga, and beech. All that is required is to underplant the desired species and kill the birch by ringing. The same is true of tall oak coppice. The successor crop develops far better than it does when the birch or oak is clear-felled, nor with gradual ringing does heather develop as is so often the case after clear felling.

European larch sometimes sows itself on heather, but it is on the whole an indifferent pioneer species. Underplanting of larch with Douglas, &c., has been undertaken with success (Dymock, Exp. Plot E. 11), but it is not clear that on that particular site a pioneer species was in fact necessary.

Japanese larch has hardly been long enough in Britain to display its full powers of natural regeneration. There are signs at Allerston that it will seed into disturbed heather sites. Plate VII*b* (Allerston Forest) shows clearly that Japanese larch has a beneficial effect on Sitka spruce on heather sites. On the wet western side of Britain Japanese larch is a first-class pioneer species growing rapidly on indifferent damp heather/grass sites, on which European larch universally fails. It rapidly improves soil conditions to a point where successor species such as Douglas fir and *Tsuga* may be underplanted with certainty of success.

The hypothesis of accelerated succession merely states that it is unnecessary in practice to spend as much time as nature would take, for example, with pine in preparing the site for spruce, Douglas, &c. Whatever the nature of the preparation, and this is discussed later, the essential part of it can be accomplished in quite a few years. If pines and spruces, &c., are planted simultaneously on a heather site, the spruces, &c., go at once into check, whereas the pine begin to grow. Emergence of the spruce, &c., from check corresponds with the development of the pine; the first signs are a greening and lengthening of the needles which will usually occur about the 8th year after planting when the pines will be

as many feet high. Next, the annual leading shoots begin to increase in length and approach normal growth towards the 12th–14th year. For a short time the spruce may need more light, which is given by cutting out the pine or slashing back the side branches, but ultimately the spruces, &c., will take the lead, and the problem arises whether to favour the pine in thinning in order to maintain a mixed plantation.

In addition to cases where the pine have been planted simultaneously with or later than successor species there are a number of examples where Norway and Sitka spruces have been planted into scrub pine (Corrour, Brendon Forest, Forest of Deer, and others). The sites are usually such as are too high and exposed for Scots pine to develop well, but sometimes are peat soils (the pine here is usually Mountain pine). In every case the spruces have shown excellent growth provided they have received sufficient light.

The spruce/beech/ash mixture on chalk illustrates very clearly the last part of the first hypothesis that a successor on one site may be a pioneer on another. While there is abundant evidence to show the succession from down grassland through native species such as thorn and trees such as *Pyrus aria* to beech forest, there is no evidence in Britain to show that Norway spruce is naturally a pioneer on chalk nor that it is naturally succeeded by beech. An obvious reason is that opportunities for the succession to take place can very rarely have arisen. Moreover, Norway spruce does not appear to seed itself well anywhere in Britain. I would be glad to hear from any forester who knows of examples or has observed the interactions of spruce and beech in limestone districts, such as the Jura Mountains.

The Silvicultural Stream

The second hypothesis opens up a very big question, covering as it does the whole silvicultural treatment of established forest crops.

In considering the succession of forest types I consulted Tansley's *British Islands and their Vegetation* and found in Chapter X on 'The Nature of Vegetation' the following lucid explanation of the natural processes:

'But on rock faces, the pioneers are confined to lithophytes, plants which can exist on relatively dry, hard, and exposed surfaces—at first lichens and terrestrial algae. These are succeeded by mosses, perennial herbs, and eventually shrubs and trees, as a soil is gradually formed and deepened by the addition of organic substance, derived from the decay of the plants, to the disintegrated mineral surface. On dry soil, as opposed to rock, the pioneers are more various in life form. Eventually, in all climates favourable to tree growth this xerosere—on rock surfaces a lithosere—culminates in climax forest. The process is essentially a progress from the pioneer vegetation which can exist on bare rock or on dry exposed mineral soil (lithophytes or xerophytes) to higher types of life form, of larger size, greater complexity and more exacting requirements. Conditioning, and also conditioned by, this progress in the type of vegetation represented by the series of plant communities, there is a corresponding development of the habitat, represented primarily by the deepening of the soil and its enrichment by organic material which gives it a greater water-holding capacity. Thus each successive population of plants prepares the way for its more exacting successor, and the habitat gradually changes and improves from an extreme dry type of

surface, fit only for the non-exacting pioneers, to a 'medial' moist type in which so-called mesophilous plants (mesophytes) can flourish.'

That description conveys to me the impression of a great stream moving slowly but relentlessly in a set direction. To move with it is easy, to move against it is a constant effort with a certain risk of return to the starting-point if the effort is relaxed. This would explain why some silvicultural operations are so expensive and unsatisfactory. As an example may be quoted the treatment of coppice. If a newly coppiced area is replanted there is usually a constant and costly struggle to prevent the rapidly growing new shoots from overwhelming the planted trees. We are metaphorically speaking paddling against the stream, and if we stop too soon we are carried back again to the starting-point; that is, the young plants are lost and the former coppice is merely repeated. Even if by constant effort the coppice is ultimately killed, it would appear that there is a deterioration in the site value (i.e. we start from a point higher up the stream) represented by such items as the dissipation of humus from the soil. On the other hand, the natural fate of coppice is for it to grow up and gradually to die off and to be replaced by successor species. As already stated, this process can be accelerated by underplanting and ringing the coppice, and in so doing there is little or no deterioration of the site.

It would appear from that example that if, in undertaking silvicultural treatment, the point of entry into the stream of succession and the direction of flow could be determined accurately the prospects of failure could be eliminated. It is suggested, therefore, that there lies here a field of ecological research which should prove fruitful to the forester.

Development of the Site. It appears from Tansley's description that there is a progressive improvement in the site as one type of vegetation succeeds another. From the forestry point of view the process may conveniently be considered in two stages divided by the time when tree species first begin to make their appearance and replace the surface vegetation. Although it seems that heather is the climax surface vegetation on certain types of soils, it is by no means certain that this is so, because it is doubtful whether any such area has been left unburned or ungrazed sufficiently long to prove the point. Two things, however, are reasonably certain: the first that poor sites which have been so maltreated that even heather cannot flourish normally are difficult even for pines (Wareham Forest is an instance), and secondly that if heather is allowed to develop undisturbed there is a gradual improvement in the site.

To take the second to begin with: heather as it passes from the short tight stage to the long stick stage undoubtedly helps to aerate the soil. The roots run well down and may occasionally be traced through an iron pan. There is possibly also a slight increase in the phosphatic contents of the soil, which the Research Branch's investigations have shown to be of great importance in promoting tree growth on poor soils. At any rate, Sitka spruce when planted pure does far better on stick than on tight heather.

The case of Wareham Forest is unusually interesting because of the work done there by Rayner (3, 4, 5, 6, 7, and 8) and Neilson-Jones (9). The former's

investigations have been fully described in a series of very interesting articles in this journal and centre largely around the mycorrhizal associations of the pines. Neilson-Jones has found an explanation of the inhibition of the growth of pines in the toxic substances formed by anaerobic bacteria. The Forestry Commission's large-scale sowings of pine at Wareham were begun in P. 26 but took an unexpected course. Germination was excellent, but for the most part the seedlings made no apparent growth at all for some years. They remained an inch or so in height with a few discoloured needles at the top. Then sporadically some died and some began to put on green needles. This process continued from year to year, while the pines which had already recovered their colour proceeded to form long needles and definite leading shoots. From an assessment of a typical sample area made in 1933 (7 years after sowing) it appeared that 29 per cent. of the seedlings were 'moving' (a few of which had been growing for 6 years but mostly only one year), 40 per cent. were still in full check, and 31 per cent. had died. In an inspection made in 1942 (16 years after sowing) it was still possible to find a few seedlings which had only recently come out of check; examples taken from Ringwood Forest adjoining Wareham are illustrated in Plate IX*a*.

At the time when this phenomenon was first under investigation a plausible explanation of the sporadic growth of pine lay in Rayner's explanation of the part which mycorrhizal fungi play. I assumed that the seed did not carry the necessary fungi, and that, although the latter might be present in the soil, time was required for seedlings and fungi to meet. Some confirmation of this view was obtained from the observation that the pines derived from sowings did develop normally in the vicinity of a few isolated old Scots pine. The work of Neilson-Jones and Rayner shows, however, that initial development can be correlated with toxic substances which inhibit first the development of mycorrhiza, which are not lacking on the original site, and by inhibiting the development of mycorrhiza also inhibit the development of the pines. My own view is that given time the seedling pines would ultimately overcome the toxity of the soil by their own action. Rayner has observed that the beneficial action of composts is 'self-propagating' among the pines, and I believe that in the same way the improvement of the site by pines is self-propagating, that is, it spreads from centres of growth (just as it does with spruces on peat soils) to the parts where the pines are in check. It remains to add with regard to Wareham Forest that the practical difficulties of afforestation have been largely solved by deep ploughing and then *planting* trees properly inoculated in nurseries. This result is largely confirmatory of both Rayner's and Neilson-Jones's conclusions.

So much for the particularly degraded soil conditions at Wareham. In discussing the more typical heather sites it is necessary to glance at the development of the technique of planting spruces. The earliest method was by vertical notching, which proved quite unsatisfactory on many sites, heather most of all; the trees went into check and stayed there. It is still possible to find spruce trees 20 years old which though still alive have grown hardly an inch since the day they were planted. Plate IX*b* illustrates the root and shoot growth of such 'checked' Norway and Sitka spruce on heather sites. Systematic examination of

the root systems showed that with notch planting the deepest roots died and the plant had to form a new and very long superficial system before it could begin to make height growth. It was concluded, therefore, that soil aeration was an important factor, and from this consideration was developed by Steven, J. M. Murray, and others the well-known system of turf planting. This worked excellently on grass sites, on which it has become the standard practice, but it did not work on heather sites. There was developed next the system of deep ploughing with caterpillars and heavy ploughs. This system was certainly an improvement in planting spruces on heather sites, but still has not come up to expectations. So finally we come to the present position, which is to plough deeply and plant mixtures of pine/spruces, &c.

HOW DO THE PIONEERS PERFORM THEIR FUNCTION?

Perhaps the most interesting point to which these considerations bring us is the way in which the pioneer prepares the way for the successor species. The most obvious effect of pine on heather sites is the opening up and aeration of the soil, but we have already seen that, although a similar effect can be as effectively or even better secured by deep ploughing, the successor species will not grow well without the pines. Tansley states that the pioneer species cause a development of the habitat 'represented primarily by the deepening of the soil and its enrichment by organic material which give it a greater water-holding capacity'. Doubtless that is what occurs in a general way, but it does not explain in any detail the mechanism of nutrition of the successor species in the pine/spruce, &c., mixtures.

There is no doubt that as the canopy closes a notable change comes over the conditions of growth. The most obvious effect is the lengthening of the leading shoot of the trees. This is noticeable not only in mixed crops on heather sites but with pure Sitka spruce on peaty soils. So much is this so that many foresters look on the closing of the canopy as a turning-point in the history of a young plantation. Not less marked are the changes which go on in the soil and on the forest floor. There is an obvious development of fungi, and earthworms and other animals make their appearance. The whole ecology of the site is modified, and in some way or other this change is connected with increased vigour of growth of the trees. It is quite possible that if we knew more exactly what is happening and could devise methods of continuing the processes at their maximum a considerable increase in timber production could be secured from the site. Too often, it appears, the processes diminish as the crop grows older.

It would doubtless be possible to found a whole system of silviculture on the theory of the succession of vegetation. Clearly it would have to be of the nature of a selection system under which single trees or small groups only were felled, because that is the only way in which one can conceive the succession proceeding uninterruptedly. That statement is not invalidated by the fact that in nature there may be catastrophic events such as fires and violent storms which bare large areas. If such places are then invaded by pioneer species, the succession just has to begin again at the beginning. There are, of course, on the Continent of Europe strong advocates of the selection system in its various forms, claiming for it an

increased production of timber. If the new crop is composed of a true successor to the old, there should be, on the arguments I have been making, strong reasons for following in their footsteps. The best and most interesting work carried out on such lines in Britain is that of Major Coke at Weasenham, in Norfolk.

In Great Britain it has been the general rule to clear-fell and replant, a process which undoubtedly leads to deterioration of the site. In the metaphor used above, the stream of succession is re-entered nearer its source and the site has to be re-developed. This is not a matter of overwhelming importance provided its existence is clearly recognized and appropriate mixtures are planted on difficult sites. There is, however, room in British silviculture for other methods than clear-felling and replanting. In the course of the war large areas will have been partially cut over and will regenerate themselves sporadically to the more valuable species, but quite frequently to the so-called weed species such as birch, which is nevertheless a valuable timber when well grown. Here then is an opportunity to practise silviculture on lines which have hitherto been neglected.

An interesting example of the retrogression of a site after felling comes within my own experience. In the Isle of Man plantations I had made in 1917 some strip fellings in poor larch about 30 feet high. The soil was a compact gravelly shale. The strips were replanted with Sitka spruce, which did remarkably well close to the standing larch, but on wide strips the growth tailed away to nothing towards the centre which in due course was invaded by heather. J. A. B. Macdonald reporting on the area in 1934 ascribed the causes of check in the spruce at the centre to drying winds. I am inclined to think, however, that the good growth on the edges of the strip was due to the biological agencies of the standing larch, and that the central zone, being a potential heather site, could have been quite successfully reafforested by a pine/Sitka spruce mixture.

On another important question, also, I am inclined to take a more reassuring view than hitherto. It has been argued frequently that the large areas which are being successfully afforested with pure spruce (Norway or Sitka) will not produce so vigorous a second crop of spruce. Time only will prove whether this will be so, but if difficulties should occur, mixed planting should go far to solve the problem.

CONCLUSION.

This article is primarily an attempt to interpret certain well-defined phenomena in the growth of mixed plantations in the light of the theory of the natural succession of vegetation, and in the second place to apply to imperfectly explored regions of silviculture similar sets of considerations. We are not yet thoroughly acquainted with the ecology of our native vegetation, and still less with the natural places which exotic species will occupy in it. There is consequently a need for systematic research in which biologists as well as foresters can play a very useful part. A beginning has been made with a scheme to establish ecological reserves on Forestry Commission properties which I propounded in the Botany Section of the British Association at Cambridge in 1938. When war broke out, a Committee was at work under Professor Salisbury selecting sites and arranging for

their supervision. I trust that it will be possible in due course to resume and expand this undertaking.

ACKNOWLEDGEMENTS.

In the compilation of this article I am indebted for the help of Mr. W. H. Guillebaud, Chief Research Officer of the Forestry Commission, who has been connected with or in charge of the research work for a number of years. I wish to thank also the various officers of the Commission who have been good enough to help with the provision of data and photographs.

LITERATURE REFERENCES.

(1) Fraser, G. K.: *Studies of Scottish Moorlands in Relation to Tree Growth.* Forestry Commission Bulletin No. 15, 1933.
(2) Tansley, A. G.: *British Islands and their Vegetation*, 1939.
(3) Rayner, M. C.: 'Mycorrhiza in Relation to Forestry. I. Researches on the genus *Pinus*, &c.' *Forestry*, viii, 1934, 96–125.
(4) —— 'Mycorrhizal Associations in Scots Pine.' *Forestry*, ix, 1935, 154–5.
(5) —— 'The Mycorrhizal Habit in Relation to Forestry. II. Organic Composts and the Growth of Young Trees.' *Forestry*, x, 1936, 1–22.
(6) —— 'The Mycorrhizal Habit in *Pinus*.' *Forestry*, xi, 1937, 117–21.
(7) —— 'The Mycorrhizal Habit in Relation to Forestry. III. Organic Composts and the Growth of Young Trees.' *Forestry*, xiii, 1939, 19–35.
(8) Rayner, M. C., and Levisohn, I.: 'The Mycorrhizal Habit in Relation to Forestry.' *Forestry*, xv, 1941, 1–36.
(9) Neilson-Jones, W.: 'Biological Aspects of Soil Fertility.' *Journ. Agric. Sci.* xxxi, 1941, 379–411.
(10) Steven, H. M.: 'The Bearing of some Ecological Conceptions on the Formation of Plantations.' *Forestry*, iv (1), 1930, 26–33.
(11) —— 'Ecological Aspects of Afforestation in the Hill Country.' *Forestry*, xii (2), 1938, 93–100.

INVESTIGATION ON THE RATE OF DRYING OF PIT-PROPS

BY W. H. GUILLEBAUD

INTRODUCTION.

ON the instruction of Sir Roy Robinson, Chairman of the Forestry Commission, a series of investigations was carried out by the Research Branch during 1940 and 1941 on the rate of drying of pit-props cut and stacked at different periods of the year and in different parts of Great Britain. Rates of drying of peeled and unpeeled props were compared, and data were also obtained on other points such as the actual and relative weights of bark.

The investigation started in January 1940 in the Forest of Dean, when 3-foot, 4½-foot, and 6½-foot props of Scots pine, Norway spruce, European larch, and Douglas fir were collected, weighed before and after peeling, and reweighed at weekly intervals. Owing to bad weather conditions it was impossible to obtain supplies of all the props at the same time and the work had to be spread over several weeks. This is a point of some importance because rate of drying is greatly affected by the date of cutting and stacking of the props. In this earliest series all the props were peeled and there was no comparative test with unpeeled props.

The second series started in May and June 1940, the work being extended to other parts of the country besides the Forest of Dean. In this series the small 3-foot props were omitted, and, except in the case of Scots pine, only one size of prop was dealt with. The whole experiment was, however, duplicated to cover the study of unpeeled as well as peeled props. See Table I for the lists of localities and species investigated.

TABLE I. *May–June series. species and size of pit-props, with location of experiment*

Species	*Size of prop*	*Date of first weighing*	*Location of experiment*
Scots pine	4½′×4″	18/19 June	Monaughty Forest, Moray
	6′×4½″	,,	,, ,, ,,
	4½′×4½″	7/8 June	Novar Estates, Ross
	6½′×5″	,,	,, ,, ,,
	4½′×4″	29/30 May	Forest of Dean, Glos
	5′×4½″	20/3 May	Alice Holt Forest, Hants
	5′×5″	4 June	Thetford Forest, Norfolk
Norway spruce	4½′×4½″	12 June	Forest of Deer, Aberdeen
	4½′×4½″	30 May	Castle Milk Estate, Dumfries
	4½′×4″	30 May	Inverliever Forest, Argyll
	4½′×4″	22 May	Forest of Dean, Glos
	5′×4½″	21/3 May	Alice Holt Forest, Hants
European larch	4½′×4″	11 June	Inverliever Forest, Argyll
	4½′×4″	29/30 May	Forest of Dean, Glos
	5′×4½″	21 May	Alice Holt Forest, Hants
	5′×5″	4 June	Thetford Forest, Norfolk
Douglas fir	4½′×4″	21 May	Invergarry Forest, Inverness
	4½′×4″	22 May	Forest of Dean, Glos
	5′×4½″	23/4 May	Alice Holt Forest, Hants
Sitka spruce	4½′×4½″	29 May	Castle Milk Estate, Dumfries

The third series of investigations was started in October 1940 and weighings were carried on until midsummer 1941. The general lines of the work were the same as in the second series, the species and localities being scheduled in Table II below.

TABLE II. *October–November series*

Species	*Size of prop*	*Date of first weighing*	*Location of experiment*
Scots pine	$4\frac{1}{2}' \times 4''$	28/9 Oct.	Monaughty, Moray
	$6' \times 4\frac{1}{2}''$	"	" "
	$4\frac{1}{2}' \times 4''$	4/5 Nov.	Ardross, Ross
	$6\frac{1}{2}' \times 5''$	5/7 Nov.	" "
	$4\frac{1}{2}' \times 4''$	28/9 Oct.	Forest of Dean, Glos
	$4\frac{1}{2}' \times 4''$	30 Oct.	Bagley Wood, Oxford
	$5' \times 5''$	4 Nov.	Thetford Forest, Norfolk
Norway spruce	$4\frac{1}{2}' \times 4\frac{1}{2}''$	31 Oct.	Forest of Deer, Aberdeen
	$4\frac{1}{2}' \times 4''$	29 Oct.	Inverliever Forest, Argyll
	$4\frac{1}{2}' \times 4''$	21/2 Oct.	Forest of Dean, Glos
European larch	$4\frac{1}{2}' \times 4''$	4 Nov.	Inverliever Forest, Argyll
	$4\frac{1}{2}' \times 4\frac{1}{2}''$	4 Nov.	Culbin Forest, Moray
	$4\frac{1}{2}' \times 4''$	23/4 Oct.	Forest of Dean, Glos
	$4\frac{1}{2}' \times 4''$	30 Oct.	Bagley Wood, Oxford
	$5' \times 5''$	5 Nov.	King's Forest, Suffolk
Douglas fir	$4\frac{1}{2}' \times 4\frac{1}{2}''$	1 Nov.	Culbin Forest, Moray
	$4\frac{1}{2}' \times 4''$	30/1 Oct.	Inchnacardoch Forest, Inverness
	$4\frac{1}{2}' \times 4''$	25/6 Oct.	Forest of Dean, Glos
	$4\frac{1}{2}' \times 4''$	28 Oct.	Bagley Wood, Oxford

METHODS OF INVESTIGATION.

The first stage in the work was the preparation and collection of the props. The unit was 100 props of a given species and size; when these had been manufactured they were delivered without delay to a suitable stacking ground and there weighed and piled (after barking in the case of the peeled props) in the usual criss-cross arrangement, on skids, in 10 layers of 10 props each. An open, but partially sheltered, site was chosen for the stacking to correspond to the conditions in a forest ride. Weighing was carried out with spring balances, each prop being weighed to the nearest quarter or half pound. The whole of the 100 props were only weighed as a rule at the beginning of the experiment; at each periodic reweighing the 20 props alone which formed the fourth and fifth layers of the stack were weighed, and each time the stack was rebuilt care was taken to see that these 20 props, which were also numbered serially, occupied the same layers in the pile. When the experiment concerned the rate of drying of peeled props, the whole of the 100 props were weighed immediately before and after peeling and then stacked; subsequent reweighings were confined to the 20 props in the centre of the stack.

The intervals between successive weighings varied in the three series of experiments and also with the class of prop. In the first series, which dealt only with peeled props, the props were reweighed every week. In the second series the

peeled props were weighed every fortnight; the unpeeled props were in two stacks of 100 props each, one of these was reweighed at the end of the first month and then peeled and weighed again, the other stack was left for 2 months and similarly treated. In the third series there were two stacks of each size of prop, one stack being peeled and the other left with the bark on; 20 props from each stack were reweighed at fortnightly intervals.

PERCENTAGE WEIGHT OF BARK.

This was the first result to be obtained from the series of experiments, as it resulted from the difference between the weights of the props before and after barking.

The results of all the weighings carried out on props over 3 feet in length barked immediately after felling are summarized in Table III below. The percentage figures given in the last column express the weight of bark as a percentage of the weight of the props before peeling.

TABLE III. *Weight of bark on pit-props*

Species	*Size of prop*	*Number of tests*	*Average weight of bark on 100 props*	*Weight of bark as a percentage of the weight of the unpeeled props*
	feet		lb.	
Scots pine	4½	1	246	8·7
	4½	7	286	8·1
	5	3	389	7·3
	6	2	487	8·4
	6½	3	655	8·4
				Average weight % 8·1
Norway spruce	4½	8	242	7·2
	5	1	417	9·4
	6½	1	450	7·6
				Average weight % 7·5
European larch	4½	1	433	16·5
	4½	6	405	13·0
	5	3	652	13·8
	6½	1	667	11·8
				Average weight % 13·2
Douglas fir	4½	1	425	16·7
	4½	6	288	10·5
	5	1	452	12·5
	6½	1	446	8·4
				Average weight % 11·2
Sitka spruce	4½	1	213	6·8

Scots Pine. The number of tests made was 16; the bark percentage ranged from 6·3 to 11·0, averaging 8·1 per cent. There is no apparent relation between length of prop and percentage weight of bark. When the lengths were averaged, it was found that the mean weight of bark per 100 lineal feet was 77¼ lb. for freshly cut material.

Norway Spruce. Ten tests were carried out. The average weight of bark was 7·5 per cent., with a range of 4·6 to 9·4 per cent. The average weight of bark per 100 lineal feet was 59 lb.

European Larch. Eleven tests were carried out. The weight of bark averaged 13·2 per cent., with a range of 9·7 to 15·5 per cent. The average weight of bark per 100 lineal feet was 104 lb.

Douglas Fir. Nine tests were carried out. The bark averaged 11·2 per cent. of the weight of the unbarked prop, the range being from 8·4 to 16·6 per cent. The average weight of bark per 100 lineal feet was 71 lb.

Sitka Spruce. There was only one test with a percentage weight of bark of 6·8.

The above data show that the proportion of the weight of an unbarked prop which consists of bark is very variable, the extreme range being of the order of 100 per cent. The actual weight of bark for any given species appears to vary with the age and more especially with the part of the tree from which the prop was cut, the weight increasing with the age of the trees and being greatest on props cut from the butt lengths.

The question also arose whether the relative weights of bark altered appreciably as the props became dry. This was tested in the May and also in some of the October series of experiments by keeping stacks of unbarked props for varying lengths of time and then peeling, the logs being weighed immediately before and after peeling. The results showed that the bark weights per cent. tend to drop 1 or 2 per cent. on the dry, or drier, logs. This decrease is probably due in the main to the loss of a certain amount of the bark as a result of frequent handling.

LOSS IN WEIGHT OF THE PEELED PROPS.

General. When the results of the three series of experiments were compared, it at once became evident that the rate of drying of the peeled props differed with the time of year at which they were prepared and that in working up the data each series must be kept separate. Moreover, in the case of the first series, carried out only in the Forest of Dean, the experiment coincided with the very severe weather (including the great Glazed Frost) of January–February 1940. Two of the four species (Norway spruce and Douglas fir) were cut, peeled, and stacked by the end of January, but the weather conditions held up deliveries of the Scots pine and European larch props, and these could not be prepared until the latter part of February. The trends of the two sets of data are so different that it would be misleading to include them under one period, and the Norway spruce and Douglas fir data have been allotted to January–February and the Scots pine and European larch to February–March periods. The second series all date from the end of May and early June and form the May–June period. The third series is classed as the October–November period of preparation and peeling. The four periods correspond roughly to mid-winter, early spring, early summer, and late autumn respectively, and each period exhibits a distinct

PLATE I

Swaffham Forest, C.47. Douglas fir, P.26, Scots pine P.27. Photo May 1942. Outside edge showing dominant Douglas fir and many smaller Scots pine.

Coed-y-Brenin Forest, C.54. Scots pine and Norway spruce, P.26. Photo May 1942. Characteristically rough Scots pine on left, a row of vigorous Norway spruce on the right.

PLATE II

PLATE III

Coed-y-Brenin Forest, C.54, P.26. Photo May 1942. Boundary between mixed pine and spruce (on the left) and spruce (on the right). The effect of the pines extends into pure spruce for three rows after which the spruce (in the foreground extreme right) are in complete check.

Thornthwaite Forest, Swinside, C.94, P.28. Photo May 1942. Scots pine and Norway spruce on a heather site 1,100 ft. elevation. Lower branches of pine slashed to admit light to the spruce. Note the vigour of the spruce foliage.

PLATE IV

PLATE V

Thornthwaite, Swinside, C.94, P.28. Photo May 1942. More general view than Plate IV, showing arrangement of planting, namely, 2 rows of Norway spruce alternating with 1 row of Scots pine.

(*a*) *Allerston II Forest. Experiment 6, P.28.* Photo April 1942. Scots pine and Sitka spruce on 3-furrow ploughing, no manures. A typical heather site.

(*b*) *Allerston II, P.28.* Photo April 1942. Sitka spruce on 3-furrow ploughing, manured with basic slag at time of planting. Note effect of Corsican pine (right) on the adjacent Sitka spruce.

PLATE VI

(*a*) *Allerston II, P.28.* Photo July 1940. Sitka spruce on complete ploughing, no manure. The dense heather is knee-high and the Sitka are still in check.

(*b*) *Allerston II, P.28.* Photo May 1942. Sitka spruce on 2-furrow ploughing and basic slag. Left Japanese larch. Note improved growth of Sitka spruce adjacent to the larch. Sitka spruce in foreground in check. A typical heather site.

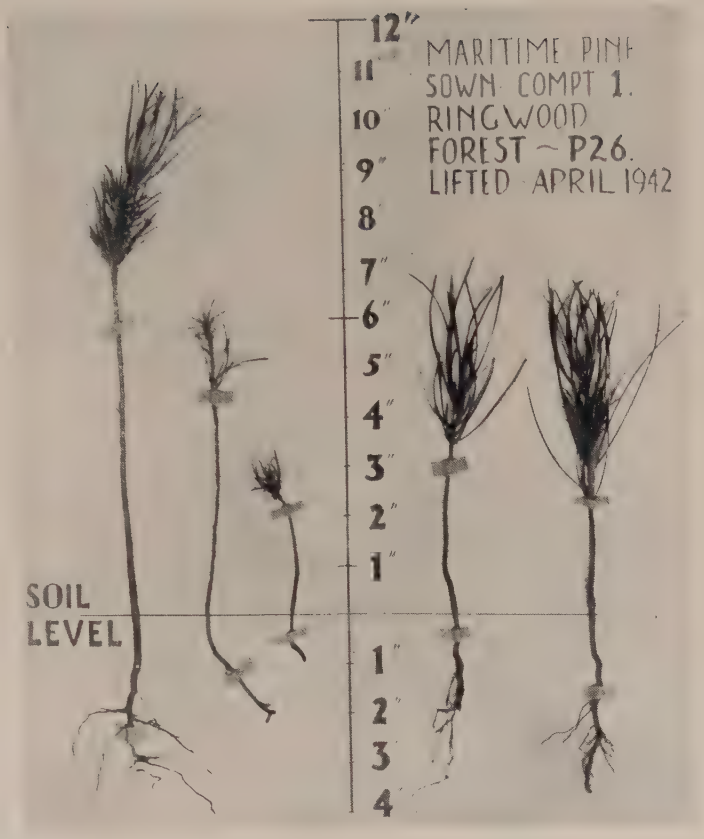
PLATE VII

PLATE VIII

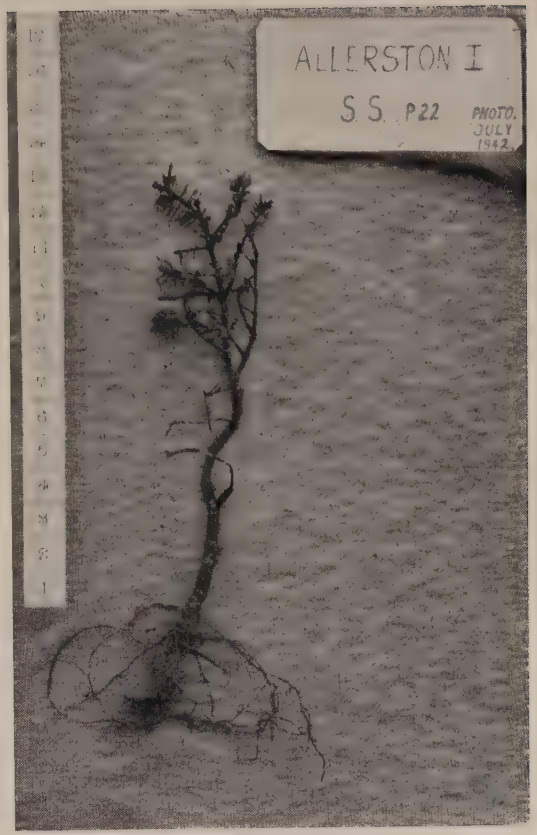
(*a*) *Teindland Forest. Experiment 16, P.27.* Photo May 1942. Sitka spruce and *Pinus contorta*. Tallest Sitka spruce 16 ft. Very poor heather site imperfectly ploughed.

(*b*) *Brighstone Forest* (*I. of W.*), *C.15, P.20* but eaten back by rabbits to ground level up to P.29. Photo May 1942 shows growth of Norway spruce left and right, vigorous ash pole on left and beech in centre. Height 20 ft. in 12 years' effective growth. Very shallow soil directly on the chalk.

PLATE IX



(*a*) *Ringwood Forest.* Sixteen-year-old seedlings from seed sown in 1926.



(*b*) Typical specimen of a 20-year-old Sitka spruce notched into heather. There has been practically no height growth. The roots have been coiled round the stem and do not show clearly the great length (15 feet is not uncommon) attained on such sites.

trend as regards rate of drying. The meteorological conditions will be discussed later.

Compilation of Data. The loss in weight of each batch of 20 props of a given species and size was expressed as a percentage of the weight of the same props before they were barked. The percentages were calculated each time the props were reweighed; the first percentage figure obtained when reweighing the props after barking represents the percentage weight of the bark, and each subsequent percentage necessarily includes this bark per cent. constant.

The next step was to plot, for each species, date of preparation and locality, the loss in weight percentages against time in days. The points were joined up and the values for the percentage loss in weight at the end of each 14 days from the date of peeling were read off. A schedule was then prepared for each species and period giving the percentage data at the fortnightly intervals; a further step was, however, necessary in order to get the whole of the data on a comparable basis. This consisted in applying the mean value for the bark percentage of each species and adjusting the data accordingly. The mean bark weight per cents. used were derived from the whole of the available data, see Table III above, and were: Scots pine 8 per cent., Norway spruce 8 per cent., European larch 13 per cent., Douglas fir 11 per cent. The final stage consisted in plotting the average loss of weight per cent. against time in days and constructing a smooth curve through the points.

The curves constructed from the averaged data are shown on Figs. 1 to 4 and the mean values read off these curves are given in Table IV below. The figures also include curves (in broken lines) for the unpeeled props; these are discussed in a later section of this report.

For each species there are three unbroken curves representing the progress of seasoning of props prepared, barked, and stacked (1) early in 1940, (2) in the early summer, and (3) in the autumn of the same year. These three curves show very different trends, and, broadly speaking, the trends are similar for each of the four species.

Props of all species (except Scots pine) cut and stacked early in the year lost weight slowly at first but then rapidly until, by the end of the 14th week, i.e. by the middle of May to the middle of June, the props had lost from 50 to 60 per cent. of their original (unbarked) weight. Douglas fir and Norway spruce peeled at the end of January dried much more slowly at first than the corresponding props of Scots pine and European larch which were not prepared until one month later. Scots pine peeled in February lost weight quite rapidly from the start. The curves for the winter peeling differ from the later series in attaining a considerably higher maximum percentage loss in weight, but it is important to bear in mind that this first series was carried out in the Forest of Dean only, while the later series include a number of different localities in England and Scotland. Reference to the data for these series shows that the Dean props consistently dried out more quickly and completely than those from most of the other localities, hence the form and high culminations of the curves for the early peeling.

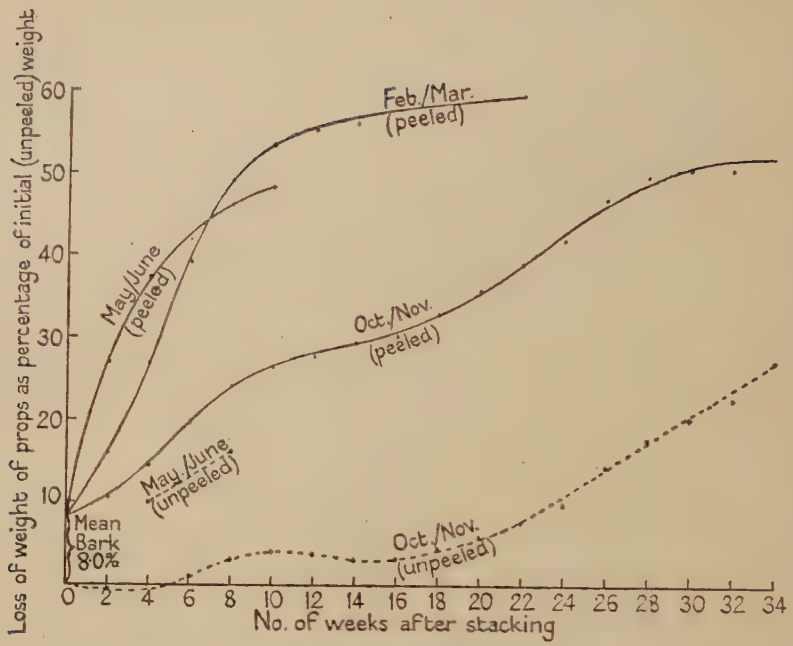


FIG. 1. Scots pine.

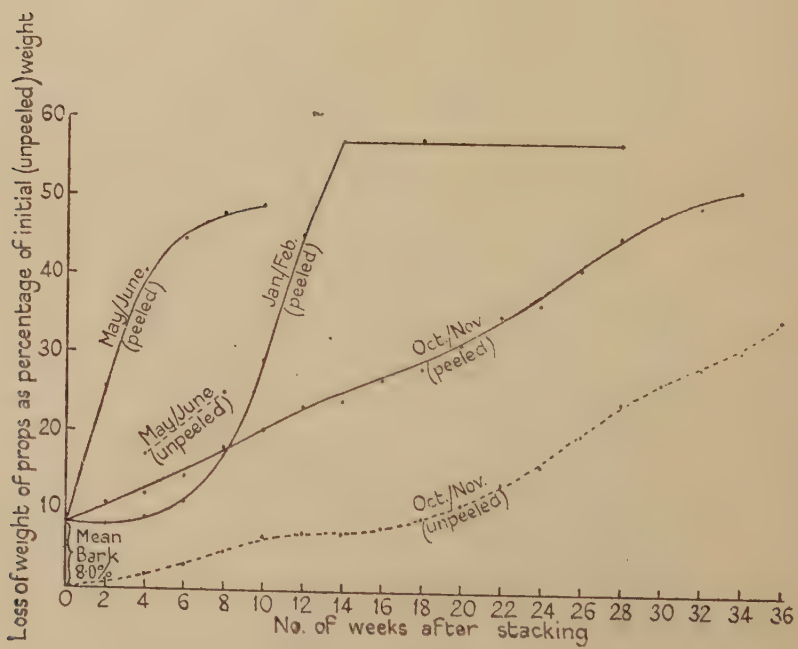


FIG. 2. Norway spruce.

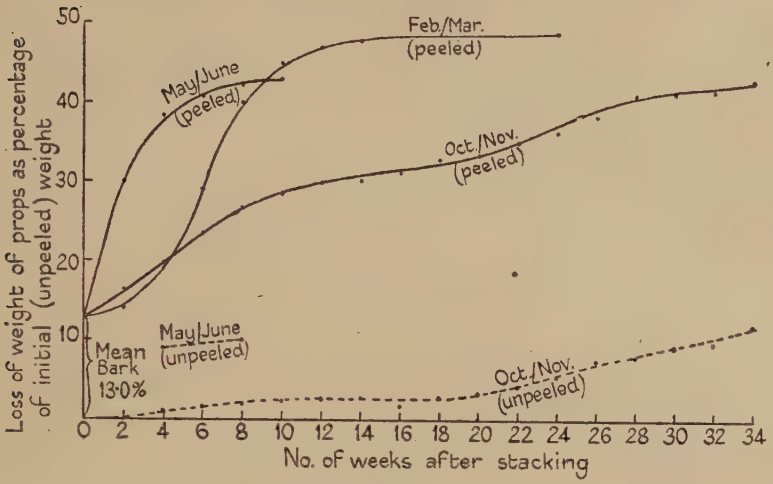


FIG. 3. European larch.

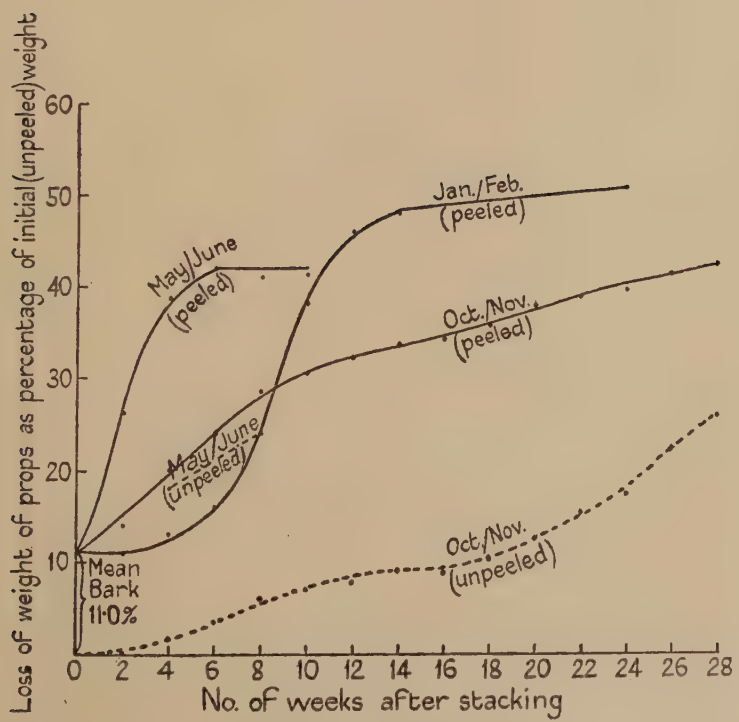


FIG. 4. Douglas fir.

TABLE IV. *Average percentage loss of weight of peeled props prepared at different dates in 1940*

Date of preparation	*Number of localities included in test*	*Percentage loss of weight after*											
		Peeling	*2*	*4*	*6*	*8*	*10*	*12*	*16*	*20*	*24*	*28*	*32 weeks*
						Scots pine							
Feb./March	1	8	16	27	39	49	53	55	57	58	..	..	..
May/June	5	8	27	37	43	46	48	..	..	..	..	..	..
Oct./Nov.	5	8	11	14	20	24	26	28	30	36	42	49	52
						Norway spruce							
Jan./Feb.	1	8	8	9	11	17	29	45	57	57	57	57	..
May/June	5	8	26	40	45	48	49	..	..	..	..	..	..
Oct./Nov.	3	8	11	12	14	18	20	23	26	31	38	46	49
						Sitka spruce							
May/June	1	7	29	40	41	42	..	..	..	..	..	..	..
						European larch							
Feb./March	1	13	14	19	29	40	45	47	48	48	49	..	..
May/June	4	13	30	38	41	42	43	..	..	..	..	..	..
Oct./Nov.	5	13	16	20	24	27	29	30	32	34	37	41	42
						Douglas fir							
Jan./Feb.	1	11	11	13	16	24	38	46	49	50	50	..	..
May/June	3	11	26	39	42	42	42	..	..	..	..	..	..
Oct./Nov.	4	11	15	20	25	28	31	33	35	38	40	43	..

In most areas the props prepared and barked in May–June lost weight very rapidly and within 2 months had reached approximate stability.

The average percentage loss of weight for all species, cut, stacked, and peeled in this summer period was 39 per cent. at the end of 4 weeks and 44 per cent. at the end of 8 weeks.

The curves for the third series of the investigation, the October–November peeling, show a very different trend from the earlier series. In three out of the four species (Norway spruce being the exception) there was a moderate loss in weight during the first 2 months, i.e. up to Christmas 1940. For example, the percentage losses in weight at the end of 4 weeks and 8 weeks respectively were as follows:

	Percentage loss of weight		
	Due to bark	*After 1 month*	*After 2 months*
Scots pine	8	14	24
European larch	13	20	27
Douglas fir	11	20	28

From Christmas onwards the rate of loss fell off markedly; the curves for Norway spruce and Scots pine show a rising tendency after about the 16th–18th week, i.e. from the middle of February. In the case of European larch this rise does not occur until a month later, while the trend of the Douglas fir remains virtually constant from the 10th week onwards. The main difference between the October–November series and the two earlier series lies in the length of time required to arrive at an approximate air-dry state. In the May–June series the props dried out more or less completely in 6 to 8 weeks. The props cut in January and February dried out in 12 to 14 weeks, but the October–November series required from 28 to 34 weeks to reach approximately the same degree of dryness.

When the October series of props in the Forest of Dean received their final weighing in July–August 1941 the experiment was considered at an end. The props, however, remained stacked up and as a matter of interest the 20 numbered props in each stack were reweighed in January 1942. The results are shown in Table V and relate to those stacks of props which were peeled immediately after the first weighing.

TABLE V

Species	*Weight of 20 unpeeled props at start of experiment Oct. 1940*	*Weight of peeled props at final weighings in July/Aug. 1941*	*Percentage loss of weight on overbark weight*	*Weight of props in Jan. 1942*	*Percentage loss of weight on overbark weight*
	lb.	lb.	per cent.	lb.	per cent.
Scots pine . . .	676	313	54	377	44
Norway spruce . .	660	286	57	326	51
European larch . .	569	292	49	340	40
Douglas fir . . .	633	348	45	377	40

The table reveals the interesting fact that the props of all four species have picked up a very appreciable amount of weight since the last weighing in the summer of 1941. The actual increases in pounds per 100 props are: Scots pine 320 lb., Norway spruce 200 lb., European larch 240 lb., and Douglas fir 145 lb. This illustrates clearly the capacity of summer-dried props to reabsorb moisture during the cold and wet winter months.

INFLUENCE OF SOURCE OF PROPS UPON THE SEASONING OF PEELED AND STACKED PROPS.

The trend of the results so far discussed has, in the case of Series II and III, been based upon averaged data from a number of different localities. Reference to the basic data shows that in a number of cases the variations due to the source of the props are very considerable. Some of the more striking cases are the following:

1. *May–June Series.*

TABLE VI. *Scots pine*

Locality	*Percentage loss of weight after*					
	Peeling	*2*	*4*	*6*	*8*	*10 weeks*
Novar, Ross	8	21	31	32	38	42
Monaughty, Moray	8	27	30	35	43	44
Alice Holt, Hants	8	25	39	46	47	48
Forest of Dean, Glos	8	29	44	48	51	52
Thetford, Norfolk	8	33	43	48	51	54
Average	..	27	37	42	46	48

In the above table the two Scottish results pair up fairly well while the three English areas form a contrasting but concordant series. Judging from these results alone, the natural tendency would be to separate the two sets of data on a geographical basis, but any such attempt breaks down with other species, *vide* Norway spruce, the data for which are given below in Table VII.

TABLE VII. *Norway spruce*

Locality	*Percentage loss of weight after*					
	Peeling	*2*	*4*	*6*	*8*	*10 weeks*
Inverliever, Argyll	8	20	30	35	39	41
Alice Holt, Hants	8	19	31	39	43	44
Forest of Deer, Aberdeen	8	29	40	42	50	50
Forest of Dean, Glos	8	25	49	55	55	56
Castle Milk, Dumfries	8	35	51	52	53	54
Average	..	26	40	45	48	49

Here the Argyllshire and Hampshire data show a very different trend from the Gloucestershire and Dumfries (Castle Milk) data. The Aberdeen area (Forest of Deer) gave an intermediate result. Clearly the geographical factor alone is not the decisive one. Equally it is difficult to explain the fact that whereas in Table VII Scots pine from Alice Holt belong to the more rapidly drying group, the Alice Holt Norway spruce props are definitely in the slow drying group.

2. *October–November Series.*

An extract from the data for one species will suffice to illustrate the variations which may occur.

TABLE VIII. *Scots pine*

Locality	*Percentage loss of weight after*								
	Peeling	*2*	*4*	*6*	*8*	*12*	*16*	*20*	*24 weeks*
Bagley Wood, Oxford	8	7	8	14	17	19	19	24	29
Forest of Dean, Glos	8	8	13	21	25	30	31	38	44
Thetford, Norfolk	8	15	22	28	33	35	39	43	47

Bagley Wood, near Oxford, is situated more or less centrally between the Forest of Dean and Thetford, and it is not obvious on any climatic basis why there should be such a big difference between the rate of loss of weight here and in the other two areas.

LOSS OF WEIGHT OF THE UNPEELED PROPS.

In the first series of the investigation, which was carried out early in 1940 in the Forest of Dean only, there were no comparative tests on unpeeled props. In the second, May–June, series, unpeeled props were stacked alongside the peeled props, but only three weighments were carried out—before stacking, after 4 weeks, and after 8 weeks. The averaged data for percentage loss of weight are shown as the upper of the two broken curves on Figs. 1 to 4. The four species lost the following proportions of their initial fresh-cut weight by the end of the 8th week: Scots pine 16 per cent., Norway spruce 25 per cent., Sitka spruce 25 per cent., European larch 10 per cent., Douglas fir 24 per cent. It is of interest to compare these results with the corresponding data for the peeled props. The comparison can be made in two ways: firstly by using the data already given for the peeled props which include the constant representing the percentage weight of the bark, and secondly by deducting the bark weight per cent., in which case the loss of weight of the two types of props represents in both cases the actual loss of moisture. See Table IX.

TABLE IX. *Percentage loss of weight of props at the end of 8 weeks, after cutting and stacking in May–June 1940*

Species	*Peeled props including percentage weight of bark*	*Peeled props excluding percentage weight of bark*	*Unpeeled props*
	per cent.	per cent.	per cent.
Scots pine . . .	46	38	16
Norway spruce . . .	48	40	25
Sitka spruce . . .	42	35	26
European larch . . .	42	29	10
Douglas fir . . .	42	31	24

The species which were slowest to dry out when stacked with the bark on are Scots pine and European larch, and these show the greatest difference between the amounts of moisture lost by the peeled and unpeeled props respectively, namely 22 per cent. for Scots pine and 19 per cent. for European larch. The unpeeled props of Douglas fir which dried out relatively quickly show a difference of only 7 per cent. (31–24) between the barked and unbarked props. The results may be summarized in the statement that unpeeled props of Norway spruce, Sitka spruce, and Douglas cut and stacked in May–June 1940 lost one-quarter of their weight at the end of 2 months. Scots pine and European larch were markedly slower in drying in the unbarked condition, but the results for European larch were perhaps unduly affected by the anomalous behaviour of the Inverliever props which failed to lose any weight during the 8 weeks.

The third series, October–November, provided more complete information on the loss of weight of the unpeeled props. The summarized data are given in Table X below and appear on Figs. 1 to 4 as the lower of the two broken line curves in each graph.

TABLE X. *Average percentage loss of weight of unpeeled props. Props cut and stacked October–November 1940*

Species	*Number of localities included in test*	*Percentage loss of weight after*											
		2	*4*	*6*	*8*	*10*	*12*	*16*	*20*	*24*	*28*	*32*	*36 weeks*
Scots pine . .	5	+1	0	1	3	4	4	3	6	10	18	22	..
Norway spruce .	3	1	2	3	5	7	7	8	11	16	24	29	35
European larch .	5	0	1	2	2	2	3	2	3	5	8	10	..
Douglas fir . .	4	0	2	3	6	7	8	9	13	18	26	..	..

Summing up the results for the two periods tested, it appears that props prepared and stacked unpeeled in early June may lose an appreciable (up to 25 per cent.) amount of their weight at the end of two months. On the other hand, if the winter of 1940–1 can be accepted as typical, it appears that props cut and stacked with their bark on in the late autumn will not lose any appreciable weight until the following spring. They may even, for a time, gain in weight.

INFLUENCE OF SOURCE OF PROPS UPON THE RESULTS OF STACKING UNPEELED PROPS.

Similar variations due to source of prop occur in the unpeeled props as have been mentioned for the peeled props. For example, in the series of props peeled in May–June 1940 unpeeled European larch props at Inverliever showed no loss of weight at the end of 2 months, the Alice Holt props showed a 9 per cent., and the Forest of Dean props a 19 per cent. loss of weight over the same period. In the autumn series there were some remarkable variations in the rate of drying of unpeeled Scots pine props in different localities. For example, at the end of 16 weeks the Ardross props showed an actual gain in weight of 7 per cent., Thetford props lost 3 per cent. of weight in that period, and the Forest of Dean props 12 per cent.

FACTORS INFLUENCING THE RATE OF DRYING OF PIT-PROPS PREPARED AT DIFFERENT SEASONS.

Presumably the factors affecting the drying of pit-props are much the same as those affecting the rate of evaporation from a free water surface, namely temperature, wind, and relative humidity of the air. Any local factor such as greater shelter from wind in one locality than another might be expected to affect the results, and it would have been advantageous if complete meteorological observations including evaporimeter readings could have been recorded in all localities in which the investigation was carried out. For various reasons this was impracti-

cable and in consequence it is only possible to discuss the question in somewhat general terms. Fortunately, the Forest of Dean, the only area in which the investigation was complete as regards the seasonal tests, possesses a meteorological station (though there is no evaporimeter), so that it is possible to give some data for this series of tests. Selecting one species, Norway spruce, Fig. 5 shows the trends of the three curves expressing the progressive loss of weight of the peeled

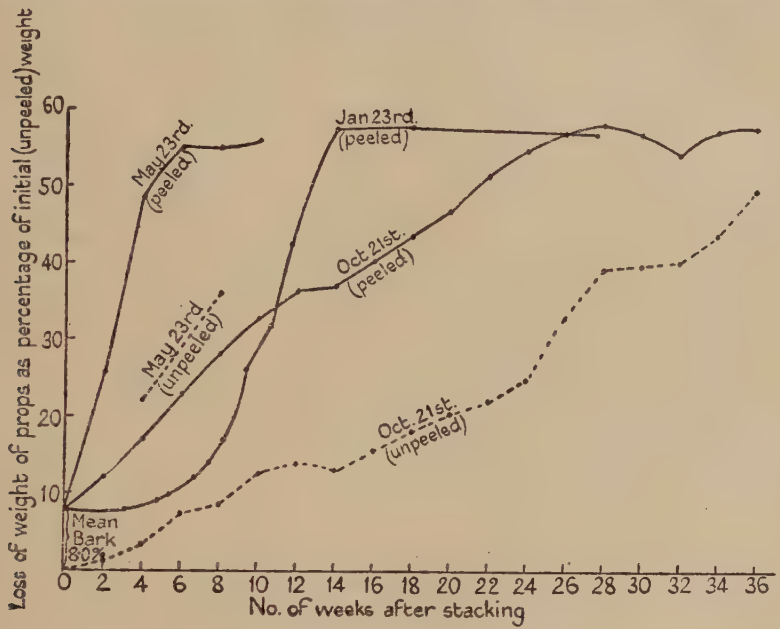


Fig. 5. Norway spruce in Forest of Dean.

props prepared at the three seasons of the year; the curves for the unpeeled props cut in May and October are also shown. It will be noted that in their general trends the curves agree with the mean curves shown in Fig. 2, which are based, as far as the May–June and October–November series are concerned, upon results from a number of different localities including the Forest of Dean.

The weather conditions can be briefly summarized as follows:

1. *January Series.*

Date of peeling, 23 January 1940. Period of test, 24 weeks. Final weighing, 8 July 1940.

Rainfall. 9·05 inches of rain fell in the first 10 weeks, but the weather was by no means continuously wet. Snow lay on the ground for some time during the first few weeks. The total rainfall over the 24 weeks was 18·60 inches.

Temperature. The mean temperature for the first week after peeling was 23° F., and for 5 weeks the thermometer remained at or below freezing-point. At the end of the 5th week the cold spell broke and the mean temperature ranged round 40° to 42° for about a month. Early in April, at about the 10th week after peeling, there was a rise in temperature with means round 46° and 47°. The 14th week

saw a further sharp rise to 52° F., the temperature remaining at or above that level until the end of the test.

Rate of Drying. During the first few weeks while freezing conditions prevailed the props failed to lose any weight, and it is not until the 7th week that the curve begins to show a definitely upward trend. The curve becomes very steep between the 8th and 10th weeks, a period of moderate rainfall (1·41 inches) with mean weekly temperatures of 41·5° and 47·5° in the 9th and 10th weeks respectively. The curve continues to rise steeply until the 14th week, the rate of drying being apparently unaffected by a rainfall of 2·09 inches in the 13th and 14th weeks. After the 14th week the curves remain at a constant level, the props having apparently lost all their free moisture.

2. *May Series.*

Date of peeling, 23 May 1940. Period of test, 10 weeks. Final weighing, 3 August 1940.

Rainfall. 4·41 inches of rain fell during the 10 weeks, but of this total only 0·87 inch fell during the first 6 weeks.

Temperature. The mean weekly temperature remained throughout the whole period between 55° and 64° F.

Rate of Drying. The hot, dry weather evidently favoured rapid drying as the props reached air-dry weight by the end of the 6th week. The curve shows no response to the heavier rainfall which occurred in the last month of the test.

3. *October Series.*

Date of peeling, 21 October 1940. Period of test, 36 weeks. Final weighing, 30 June 1941.

Rainfall. 12·48 inches of rain fell in the first 10 weeks and 28·58 inches over the whole period. There was one very wet period just after the props were stacked when there was a fall of 7·47 inches in a fortnight, and two dry spells, the first between the 8th and 14th weeks (rainfall of 1·72 inches) and the second between the 20th and 30th weeks (rainfall of 2·07 inches).

Temperature. For the first 3 weeks after the experiment was started the mean weekly temperature fluctuated round 45° F.; thereafter it dropped steadily until it reached its lowest point for the winter of 31° for the week ending 13 January (12th week of test). During the next 3 months the weather remained cold with mean temperatures at or slightly below 40° F. At the beginning of April, in the 25th week of the test, the mean temperature rose to 45·6°, in the 32nd week the mean temperature was 52·1° F., and in the 36th week 61·5° F.

Rate of Drying. The trend of the October peeling curve is remarkably uniform, apart from the two breaks which occur at the 12th–14th and 30th–34th weeks respectively. A certain amount of drying took place in the first fortnight despite the heavy rainfall and thereafter the curve for the peeled props rises steadily, in spite of the gradually falling temperature, until the end of the 12th week, the week in which the mean temperature dropped to below 32° F. The break which then occurs is more pronounced still in the curve for the unpeeled props (broken-

line curve on Fig. 5) and can scarcely be explained by the cold weather of the 12th week as that was already over and is probably due to the fact that rain fell on the day of weighing at the end of the 14th week and increased the weight of the props. The steep rise in the curve for the unpeeled props between the 24th and 28th weeks coincides with a period of low rainfall with mean temperatures mostly over 45° F. The upward trend of the curve for the peeled props over the same period is much more gradual, but it is evident that they were then approaching the air-dry condition. Between the 28th and 34th weeks the curves for the peeled as for the unpeeled props show a check the reason for which is not apparent. Temperatures were relatively high and rainfall low. Some error in weighing might be suspected but for the fact that the curves for the other three species, Scots pine, European larch, and Douglas fir (not reproduced), all show the same pronounced dip at this point. Examination of the values for the depression of the wet bulb thermometer over this period showed that relative humidity was abnormally high between the 28th and 32nd weeks, and this factor may account for the curious behaviour of the curves.

The conclusion from the meteorological evidence available is that while there is a general relation between rate of loss of weight of stacked props and mean weekly temperatures, the correlation is by no means exact. The influence of rainfall is much harder to detect. There is no evidence that rainfall during the summer months has any marked effect upon the rate of drying; on the other hand, in winter, rain, more especially snow in combination with low temperature, can slow up or check entirely the loss of moisture from stacked props.

Examination of data from other areas in which the investigation was carried out seems to indicate that the striking differences found in the rates of loss of weight of the same species in different areas cannot be wholly ascribed to climatic variations. It seems probable that other factors such as the age of the trees from which the props are cut, the part of the tree, i.e. whether the butt length or the upper part of the pole, and possibly also characters inherent in the timber itself, play some part in determining the rate at which the props will lose weight under any given set of meteorological conditions. A much more searching investigation than the present would be needed to confirm these suggestions.

PRACTICAL CONCLUSIONS.

Assuming that the weather conditions during 1940 and the first six months of 1941 can be regarded as relatively normal, the following conclusions can be drawn:

1. The optimum period for the preparation of peeled props is given by the spring and summer months, say from the middle of April to the middle of September in the warmer parts of the country. Props prepared and carefully stacked during this period may be expected to lose 75 to 80 per cent. of their free moisture within one month of stacking and to become approximately air-dry within 8 to 10 weeks. In the colder and wetter parts of the country, e.g. most of Scotland and at the higher elevations in England and Wales, the optimum period is probably curtailed somewhat at both ends. The early months of the year—

January to April—represent a generally less favourable period for rapid drying. Any prolonged spell of frosty or snowy weather will be liable to hold up the process of seasoning more or less completely and the props may require 2 to 3 months before they lose 80 per cent. of their free moisture. The least favourable period for the preparation of props is the late autumn, as it may take 5 months for props peeled at this season to get within 20 per cent. of their final (air-dry) weight, though much may depend on the weather conditions in any particular year and locality.

It should be observed that the above conclusions are to some extent at variance with the findings of the Forest Products Research Laboratory at Princes Risborough.[1] This laboratory carried out in 1926 and 1927 an investigation on the rate of drying of stacked props the results of which are summarized in the statement on page 7 of their Bulletin: 'Props felled early in the year, peeled and properly piled, will dry sufficiently in six or seven months, and should be disposed of for use during the following late summer or autumn. Those felled in early winter, taking a little longer to dry, are ready for disposal at about the same time as those felled in early spring.' The present investigation indicates a much quicker rate of drying than could be inferred from the above statement, and this discrepancy serves to emphasize the importance of seasonal conditions.

2. Effect of removing the bark. The effect of peeling the props before they are stacked results firstly in an immediate loss of weight amounting to from 8 to 13 per cent., according to species, and secondly in a much increased rate of drying. The effect appears to vary considerably with the species, Norway spruce and Douglas fir drying out relatively quickly when stacked with the bark on, while Scots pine and European larch are very slow to lose weight; in fact props of both species are liable to gain a certain amount of weight if cut, and stacked unbarked, in the autumn. If rapid loss of weight is a desideratum, peeling is clearly advisable.

3. Given that peeling is necessary in order to get quick drying, the cost of peeling and stacking must be more than offset by the economic advantages of producing light peeled props. Peeling and stacking adds approximately 25 per cent. to the cost of pitwood; the cost being taken to include the price of the timber, manufacture of the props, and delivery to the nearest railway station. Advantages of peeling and seasoning include: greater ease of handling and cheaper haulage to station, easier handling in the pit, reduced railway freight (though this depends on the size of wagon used), and greater strength in compression. As to this last point, the Forest Products Research Laboratory state that there is no substantial increase in strength until the moisture content of the props has been reduced to below 30 per cent., a figure which is not reached until the props are thoroughly seasoned. The Bulletin also points out that completely seasoned props are not always welcomed by the miners because, though stronger than partially seasoned props, they are liable to break without warning. It would appear that the principal if not the only advantage gained by peeling and stacking pit-props lies in the reduction in haulage and freight charges.

[1] Bulletin No. 9, 1931, of Forest Products Research, Department of Scientific and Industrial Research, entitled *Home-Grown Pit props.*

MISCELLANEOUS RESULTS.

The following subsidiary information was obtained in the course of the investigation.

1. *Influence of Size of Prop upon Rate of Seasoning.* In addition to the standard 4½ to 5 feet props which were produced in most of the areas taking part in the seasoning investigation, parallel series were carried out in some cases using larger or smaller props than the standard. In the first set of experiments carried out in the Forest of Dean stacks of 3-foot and 6½-foot props were kept under the same conditions as the 4½-foot props and reweighed at similar intervals. The results are set out in the following table. The data relating to the 3-foot Norway spruce and 4½-foot European larch props are omitted as these were not prepared and stacked on the same dates as the other props of these species and so the results are not strictly comparable.

TABLE XI. *January–March series in the Forest of Dean*

Species	*Length of prop*	*Percentage loss of weight of peeled props after*					
		Peeling	*2*	*4*	*8*	*12*	*14 weeks*
	feet						
Scots pine	3	8	14	33	57	59	59
	4½	8	16	27	49	55	56
	6½	8	16	24	41	51	53
Norway spruce	4½	8	8	9	16	45	57
	6½	8	8	8	19	40	48
European larch	3	13	29	33	57	59	59
	6½	13	20	26	42	47	48
Douglas fir	3	11	11	13	27	47	52
	4½	11	11	13	24	46	48
	6½	11	11	13	24	45	49

There is a general tendency—most marked in the pine and larch and less so in spruce and Douglas fir—for the smaller props to season more rapidly and possibly more completely than the larger ones. In the two later series of tests two sizes of Scots pine props (4½ feet and 6 or 6½ feet) were studied in the north of Scotland; the results bore out the earlier findings in the Forest of Dean, but the differences were smaller, the larger props being seldom more than 2 to 3 per cent. behind the smaller ones at any given date.

2. *Weight of Props of Different Species and Sizes.* Table XII sets out the average number of props per ton for each of the species and prop sizes examined.

This table is merely another way of expressing the data which have already been given in the tables and diagrams of percentage loss in weight; comparison between the third and fifth column of Table XII shows how great is the effect of peeling and seasoning upon the number of props of any given size which go to make a ton.

Apart from the 4½-foot props the data are too scanty to enable valid conclusions to be drawn as to the relative weights of props of the species concerned. Considering the 4½-foot props alone, if the weight of the freshly prepared peeled

Scots pine prop is taken as 100 the weights of the corresponding props of the other three main species are: Norway spruce 96, European larch 77, Douglas fir 75. Assuming that the props were all cut according to specification it appears that Scots pine made the heaviest and Douglas fir the lightest props in this series of tests.

TABLE XII. *Average number per ton of props of different species and sizes*

Species	*Sizes of prop*	*Number of tests*	*Average number of props per ton*		
			Freshly prepared		*Peeled and stacked until approx. air-dry*
			Before peeling	*After peeling*	
	feet				
Scots pine	3	1	132	147	347
	4¼	1	79	87	174
	4½	7	63	69	130
	5′×4½″	1	51	55	104
	5′×5″	2	39	42	89
	6	2	38	41	71
	6½	3	29	31	58
Norway spruce	3	1	195	206	457
	4½	8	67	72	143
	5	1	50	55	91
	6½	1	36	38	78
Sitka spruce	4½	1	72	77	132
European larch	3	1	175	189	373
	4¼	1	85	102	137
	4½	6	77	90	145
	5′×4½″	1	57	67	102
	5′×5″	2	44	51	80
	6½	1	37	41	78
Douglas fir	3	1	185	210	380
	4¼	1	88	106	154
	4½	6	82	92	151
	5	1	64	73	120
	6½	1	39	42	78

SUMMARY.

1. A series of investigations on the rate of drying of pit-props was carried out by the Research Branch of the Forestry Commission during 1940 and 1941.

2. The first series started in January–February 1940 in the Forest of Dean, the second series started in May–June 1940 when the investigation was carried out in 9 separate localities in Great Britain. The third series, which began in October 1940 and extended into 1941, covered 10 different localities.

3. The species investigated were Scots pine, Norway spruce, Sitka spruce (one test only), European larch, and Douglas fir, but all these species were not used in each locality.

4. Tests were carried out on unpeeled as well as peeled props; the props were weighed when freshly cut and then at regular, usually fortnightly, intervals, until

they had reached, in most cases, constant weight. Each test was based on the weight of 20 props taken from the centre of a stack of 100 props.

5. Information has been obtained on the weight of bark on props of the different species and sizes of props investigated.

6. Rate of drying has been expressed in terms of percentage loss of weight, these percentages being calculated on the weight of the freshly prepared, unbarked props.

7. Tables are given showing the progressive loss of weight of the props prepared and stacked at each of the three seasons in which tests were started, namely winter, midsummer, and late autumn.

8. It is shown that the rate of drying was greatly affected by the time of year at which the props were prepared, drying being most rapid in the summer series, somewhat slower in the winter series, and very gradual in the third series in which the props were cut in the autumn of 1940. The behaviour of peeled and unpeeled props is also compared.

9. Somewhat varying results were obtained from the different localities; these are discussed in the paper.

10. The factors influencing the rate of drying of props prepared at different seasons are discussed with special reference to the work carried out in the Forest of Dean. Minor fluctuations in weight occurred which are difficult to interpret in relation to the meteorological data available.

11. Practical conclusions are drawn from the results of the investigation.

12. Information was obtained on two subsidiary points, firstly, the influence of size of prop upon the rate of seasoning, and secondly, the average number per ton of props of different species and sizes when freshly prepared and after peeling, stacking, and seasoning.

ANISOTROPIC CONTRACTION OF WOOD AND OF ITS CONSTITUENT CELLS

BY R. D. PRESTON

(*Department of Botany, University of Leeds*)

INTRODUCTION.

THE timber technologist and the forester, in virtue of the complex polyphase nature of the material with which they deal, are confronted by an array of varied problems of a peculiarly intricate nature. Data obtained in attempts to solve these problems are seldom easy of unambiguous interpretation and their interrelation is often far to seek. It is the purpose of the present paper to emphasize a point which is already in the minds of many workers of this field but with occasional exceptions has not been explicitly stated. Just as the physical and chemical properties of *inorganic* material in the mass arise as a consequence of the structure of the molecules of which the material is composed, so must the properties of an *organic* material depend on the precise nature of the molecules and molecular aggregates present. The properties of timber will thus represent not only an integration of those of the individual cells composing it, but also, and even more fundamentally, of the physical nature of the complex molecules constituting the cell wall. It seems inevitable, in fact, that a complete understanding of the properties of timber, and of many of the features of a standing tree, can be reached only through a thorough study of the molecular structure of the cell walls of the constituent cells. Such a correlation will necessarily involve an integration over first the individual cell and then over timber in bulk, but, in general and especially if broad outlines are aimed at rather than meticulous detail, the difficulties involved should not be insuperable. It is already clear that wall studies place in the hands of botanists a tool of the utmost usefulness and value, and the same should also be true of the forest technologist.

In the following pages a suggestion is made how this integration may be achieved in the case of one specific property of timber—anisotropic contraction or shrinkage—and to consider whether, in view of the fundamental nature of this property, other properties both of timber and of growing wood can be connected with it. Recently the anisotropic contraction of wood has received some attention at the hands of Vintila (30) and Frey-Wyssling (8, 9) for normal wood, and of Münch (21) for 'reaction' wood. It has already become clear that the swelling and contraction of cell walls is largely controlled by the chemical and physical nature of the cellulose composing them (16, 17, 26), and it would seem natural, therefore, to assume that the swelling and contraction of wood is to a large extent controlled by the structure of the cells of which it is composed. The connexion between wall structure and contraction should manifest itself most markedly in the case of conifer wood which, with the exception of ray tissue, consists of a

system of similar cells similarly arranged. It is, therefore, at first sight disheartening to find an eminent authority like Frey-Wyssling denying to wall structure any part in determination of anisotropic contraction (9) in spite of an earlier interpretation (8) of this phenomenon in terms of wall-structure determinations carried out by the writer (22). The implications of this work will be discussed later, but it may be pointed out at the outset that Frey-Wyssling, while rejecting on sound reasoning the conclusions of the earlier workers, fails entirely to prove his own case. This work on the contraction of wood, together with the writer's own work on swelling, has recalled a very pertinent series of determinations made some years ago by the writer for another purpose. This work was not published at the time, but its very evident connexion with the present problem has stimulated its further interpretation, particularly since it leads very definitely away from the opinion given by Frey-Wyssling.

The technique available for the present study does not allow the collection of very numerous results, and admittedly the data are somewhat meagre. They do, however, allow a number of general conclusions to be drawn in a most encouraging way and lead the way to further research of a more detailed nature which is being undertaken in this laboratory with a new technique capable of yielding more information. It is fully realized that a study of this kind is beset with pitfalls; the results are presented at this time both because further results may not be available for some considerable time, and because the conclusions reached may be of interest to workers in such a wide field that it seems justifiable to accept the risk of making minor errors of detail. In the following pages it is suggested that anisotropic contraction in single cells is quantitatively to be accounted for by the contraction of their cellulose matrices; and that, further, the contraction of wood is to be accounted for on similar lines as far as can be judged from the figures available. Finally, it would appear that the development of tensions in the wood of standing trees and timber is not unconnected with the present problem, and it seems possible (though this will not be considered further at this time) that an explanation of the phenomenon of spiral grain will eventually be derived.

It is not proposed here to give any but the briefest outline of modern views concerning the structure of cellulose, and the reader is referred to the various reviews which have been published (1, 6, 23). Cellulose consists of long chains of β-glucose residues at least 600 Å[1] long (and probably far longer) united into ill-defined bundles about 50 Å diameter in which the chains lie strictly parallel. The chains in one such 'micelle' are considered to pass over into neighbouring micelles with the effect that the regions between the micelles (the 'intermicellar spaces' of the classical Micellar Hypothesis) are traversed by chains running in more or less random fashion. The chains are held together by forces which individually are of the order of those uniting two molecules together in a gas, but there are so many of these forces per chain that the whole structure is very firm. Scattered throughout this system, long narrow gaps occur whose dimensions grade up from that of the 'intermicellar' spaces (i.e. of the order of thickness of the micelles) to some unspecifiable upper limit possibly of the general order of size of the

[1] 1 Å = 1/100,000,000 cm.

plasmodesmata—the wall is heterocapillary (7). Such a structure, bristling with the hydrophillic —OH groups along the length of each chain in the interstices and along the surface of the micelles, will clearly swell most markedly in the transverse plane when immersed in water. On the other hand, the molecular chains themselves will not increase in length; but the occasional chain ends and, far more important, the frequently observed angular dispersion of the micelles (17, 24) causes a small longitudinal swelling of the order of 2 per cent. (13) or less (12). Lateral swelling is usually of the order of 20 per cent., but both values may differ from those given here in different cell types.

The cellulose complex itself is thus characterized by anisotropic swelling and contraction, and is bound to impose on the cell wall as a whole some degree of anisotropy. It seems in fact highly probable that the swelling properties of a cell are quantitatively to be accounted for by the swelling properties of the cellulose in terms of the directions of its chains in the walls. This is the point to be tested in the present paper. The observations, like those of Frey-Wyssling, consist of dimension changes involved in drying rather than in wetting, and of corresponding directions of cellulose chains, in fibres of hardwoods and tracheides of softwoods. The latter property is determined optically under the polarizing microscope by a method in general use and already described elsewhere (22).

MATERIALS AND METHODS.

Fibres were used from four hardwoods—*Tilia*, *Acer*, *Ulmus*, and *Fraxinus*—and tracheides from four softwoods—*Taxus*, *Cupressus*, *Pinus*, and *Cedrus*. In each species spring and summer wood was investigated independently, but since there was no observable difference between these two regions of the wood as far as the present paper is concerned these observations are pooled. It will, in fact, be shown that the softwoods as a whole and the hardwoods as a whole are so uniform that they may be treated as two whole groups.

A major disadvantage of the present method of determining the inclination of cellulose micelles in a wall lies in the fact that the cell must be cut open at some region. This introduces the difficulty that intact cells cannot therefore be used in the length determinations, and this is one of the points to be remembered in the development of a new technique. In the present case thin sections were prepared somewhat off the longitudinal, macerated in 5 per cent. chromic acid, washed in distilled water, and mounted on a slide previously smeared with albumen fixative. A dilute solution of glycerine was used rather than water as mounting medium, since the increased viscosity then prevented the free movement of cells so troublesome in water alone without reducing the hydration of the cells to an undesirably low figure. Cells were selected, attached to the slide by one end only, from which sufficient of one wall had been removed to allow the determination of the major extinction position (m.e.p.)[1] and this position and the length of the fibre (portion) were observed. The slides were then transferred through a graded series of alcohol-water mixtures to absolute alcohol and the m.e.p. and length

[1] In a wall consisting of only one set of cellulose chains such as we probably have here (22, 24) the m.e.p. corresponds in direction to the cellulose chains.

again determined. The cells were finally replaced in the aqueous medium and the determinations repeated. It was found preferable to make a separate determination of cell breadth on duplicate samples.

RESULTS.

The results are presented in Tables I and II. No separate figures are given of breadth measurements; it is notoriously difficult to estimate accurately the breadth of cells of the present type under the microscope, and no great accuracy can be claimed for individual measurements. As a result of some 100 measurements in each case, however, it appears that the diameter of the hardwood fibres in the glycerine water mixtures used here is about 13 per cent. greater than when mounted in alcohol, while the corresponding figure in the case of the softwoods is 18 per cent., and these figures alone will meet the demands of the present paper. It is to be noted that the m.e.p. is always inclined to the long axis of the cell at a considerable angle and in the cell as a whole is therefore arranged along a spiral. The behaviour of the m.e.p. differs in the two groups. In the hardwoods dehydration leads to an increase in the inclination except in the region of 40° and above where it remains constant. In the softwoods, on the other hand, the inclination remains constant throughout with a slight tendency to decrease at inclinations less than 40°. The spiral arrangement of the m.e.p. would lead us to expect always a decrease in inclination on dehydration, and it is difficult at the moment to harmonize this divergent behaviour with any certainty. It is to be remembered, however, that the m.e.p. is determined in those parts of the wall which have been cut open and the response to dehydration is probably governed by the particular shape of the cut end of the cell. The m.e.p. determined in the aqueous medium will be closely similar to that in the intact part of the cell, but the same condition may not hold after dehydration. While therefore we may legitimately attempt to explain the changes in cell dimension in terms of the original inclination of the m.e.p., it would be unsafe to draw any conclusions from its inclination after dehydration, and this latter measurement will therefore not be discussed further until more decisive data have been obtained.

It is to be noted that in Tables I and II both softwoods and hardwoods show not only contraction in girth but also a contraction in length on dehydration, up to cells with an inclination of about 40°. If the inclination is greater than 40° (i.e. if the spiral is flatter) either the cell elongates on dehydration or, more commonly, the length does not change. This is at first sight rather remarkable behaviour and demands detailed discussion. We are accustomed to think of dehydration (in, for instance, stretched rope or string) as inducing *elongation* in material with spiral organization. It will be seen later, however, that a spirally wound cell can respond to dehydration in either direction, dependent on the initial inclination of its micelles.

TABLE I. *Hardwoods*

Fibres from	*Inclination of m.e.p. to longitudinal cell axis (degrees)*			*Length (scale divisions)*		
	Glycerine-water	*Alcohol*	*Glycerine-water*	*Glycerine-water*	*Alcohol*	*Glycerine-water*
Acer	40·2±1	39·9±1	..	10·35±·003	10·32±0·03	..
	46·4±1	46·0±1	..	9·72±0·01	9·72±0·01	..
	36·9±1	44·0±1	38·2±1	11·39±0·01	11·20±0·01	11·40±0·01
	37·7±1	42·7±1	41·0±1	8·56±0·01	8·36±0·01	8·40±0·01
	36·0±1	39·2±1	36·0±1	6·62±0·01	6·50±0·01	6·60±0·01
	35·8±1	38·7±1	36·0±1	8·11±0·01	7·65±0·01	8·11±0·01
	30·0±1	37·2±1	31·3±1	10·98±0·02	10·84±0·02	10·97±0·01
	28·2±1	40·0±1	39·4±1	8·30±0·01	7·60±0·01	7·70±0·01
Ulmus	40·2±1	44·2±1	40·0±1	7·38±0·01	6·90±0·01	7·20±0·01
	39·9±1	39·2±0·5	38·9±1	11·57±0·01	11·60±0·01	11·65±0·01
	39·0±1	39·0±1	..	13·60±0·01	13·60±0·01	..
	36·0±1	39·3±1	38·3±1	11·33±0·06	11·20±0·02	11·20±0·02
	35·5±1	38·5±1	39·0±1	10·39±0·01	10·26±0·01	10·24±0·01
	33·3±0·5	38·2±1	36·9±0·5	10·45±0·03	10·35±0·02	10·32±0·02
Tilia	44·8±1	44·6±1	..	11·53±0·01	11·52±0·01	..
	43·8±1	43·0±1	..	14·20±0·01	14·10±0·01	..
	40·4±1	38·8±0·6	40·8±1	7·01±0·01	7·27±0·01	7·03±0·02
	39·2±0·5	39·8±0·5	..	23·70±0·01	23·70±0·01	..
	35·2±1	40·6±0·5	38·4±1	7·71±0·01	7·60±0·01	7·63±0·01
	34·6±1	38·2±1	38·0±0·5	10·01±0·01	9·78±0·01	9·90±0·01
	32·0±1	38·4±1	36·4±1	12·24±0·02	11·82±0·02	11·96±0·02
Fraxinus	41·5±0·5	41·8±1	..	6·23±0·01	6·30±0·01	..
	38·8±1	39·0±1	..	11·70±0·02	11·72±0·02	..
	32·2±0·2	31·9±1	..	6·79±0·01	6·80±0·01	..
	28·5±1	30·9±1	29·0±1	10·40±0·01	10·12±0·02	10·30±0·01
	24·7±1	33·6±1	31·8±1	8·16±0·01	7·30±0·01	7·32±0·01
	23·4±1	27·2±0·5	25·0±0·5	11·30±0·02	11·01±0·01	11·10±0·01
	23·0±0·5	27·6±1	24·1±0·5	13·93±0·01	13·42±0·02	13·94±0·01
	21·7±1	27·5±0·5	27·1±0·5	9·11±0·01	8·69±0·01	8·68±0·01
	21·1±1	27·7±0·5	22·0±0·5	14·00±0·02	13·68±0·02	13·88±0·02
	21·1±1	28·8±0·5	28·7±1	14·12±0·02	13·90±0·02	14·01±0·01

DISCUSSION.

(*a*) *Length Changes in Individual Cells.*

This outstanding feature of the length relationships is clearly the first to demand attention. It will be clear from Fig. 1 (*a*) that contraction in girth of a cylindrical cell wound with a molecular spiral whose length along the spiral is constant involves of necessity an *increase* in length, and this is the condition commonly observed in spiral structures. If, on the other hand, the spiral winding itself contracts in length on dehydration, then we have the possibility that this contraction may annul or even override elongation of the cylinder associated with girth decrease, and the cylinder may then contract (Fig. 1 (*b*)). In view of the statement that the cellulose matrix is supposed to contract about 2 per cent. in

the direction of its chains (13), this latter possibility seems worth further investigation in the light of the cell-length contraction observed here. Our first problem is to estimate the percentage contraction in length of the spiral windings of the walls under consideration. This may be done in the following way.

TABLE II. *Softwoods*

	Inclination of m.e.p. to longitudinal cell axis (degrees)		*Length (scale divisions)*	
Tracheide from	*Glycerine-water*	*Alcohol*	*Glycerine-water*	*Alcohol*
Pinus	47·9±1·0	48·0±1·0	32·38±0·05	32·36±0·05
	46·9±0·5	47·3±0·5	22·50±0·01	22·48±0·01
	46·1±0·5	46·0±0·5	27·10±0·02	27·00±0·02
	46·0±0·5	45·9±0·5	20·40±0·03	20·43±0·04
	45·3±1·0	45·0±0·5	25·37±0·03	25·30±0·04
	44·7±0·5	42·5±0·5	21·71±0·01	21·70±0·01
	44·3±0·5	44·4±0·5	23·50±0·02	23·60±0·02
	43·8±0·5	43·5±0·5	29·68±0·08	29·56±0·07
	43·4±0·5	43·5±0·5	26·52±0·02	26·52±0·02
	34·9±0·5	29·7±0·5	28·78±0·04	28·68±0·01
Taxus	49·5±1·0	44·2±1·0	34·13±0·08	33·80±0·04
	47·9±1·0	47·2±1·0	32·30±0·04	32·20±0·08
	44·9±1·0	43·9±1·0	19·05±0·04	19·25±0·05
	40·8±1·0	42·0±1·0	10·55±0·01	10·59±0·02
	38·4±0·5	40·2±0·5	21·10±0·02	19·84±0·02
	35·9±0·5	33·6±0·5	9·71±0·01	9·60±0·01
	32·6±0·5	33·6±1·0	24·15±0·01	24·22±0·02
Cupressus	44·9±0·5	44·2±0·5	47·92±0·06	47·88±0·04
	43·0±1·0	..	14·92±0·02	15·03±0·02
	42·9±0·5	42·4±0·5	14·75±0·01	14·75±0·01
	38·7±0·5	39·3±0·5	24·60±0·02	24·40±0·02
	33·7±0·5	34·4±0·5	14·39±0·01	14·01±0·01
	33·0±1·0	36·4±0·5	15·80±0·03	15·40±0·01
	32·0±1·0	35·0±0·5	24·62±0·02	24·16±0·01
	27·8±0·5	27·5±0·5	17·20±0·01	16·92±0·01
	27·5±0·5	28·2±0·5	34·52±0·04	34·38±0·04
	23·7±0·5	22·5±0·5	9·06±0·01	8·80±0·05
Cedrus	54·0±1·0	55·0±1·0	11·45±0·05	11·50±0·05
	47·6±0·5	47·5±0·5	16·47±0·03	16·44±0·04
	45·5±0·5	45·0±0·5	14·23±0·03	14·25±0·02
	41·6±0·5	30·5±0·5	25·40±0·04	25·37±0·05
	40·4±0·5	41·4±1·0	35·69±0·03	35·54±0·02
	39·5±0·5	39·8±0·5	17·10±0·02	17·00±0·02
	39·3±0·5	39·0±0·6	11·55±0·05	11·55±0·04
	38·6±0·5	39·5±0·5	38·92±0·03	38·90±0·04
	38·6±0·5	41·5±0·5	27·25±0·02	27·19±0·02

Let b_1, Fig. 1 (*b*), represent the girth of a cell in an aqueous medium, l_1 the length of the spiral winding corresponding to one complete turn, h_1 the pitch of the spiral, and θ, the inclination of the spiral to the longitudinal cell axis. Let

the corresponding values of the same cell after dehydration be b_2, l_2, h_2. Then we have the relations:

$$h_2^2 = l_2^2 - b_2^2, \tag{1}$$

$$h_1^2 = l_1^2 - b_1^2 = l_2^2(1+y)^2 - b_2^2(1+x)^2, \tag{2}$$

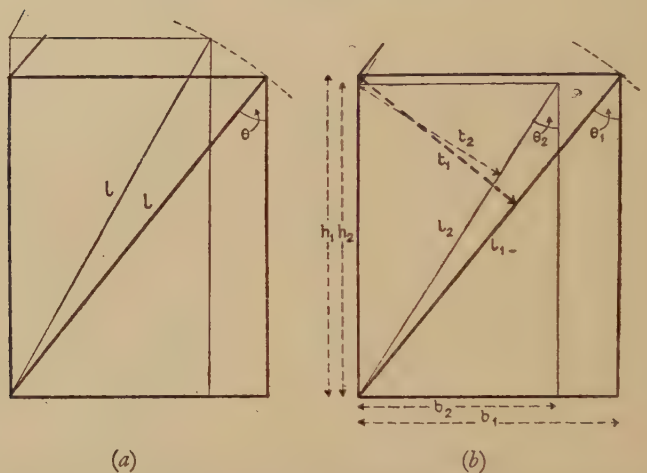
where x and y are the relative contractions of the girth and spiral windings respectively, expressed in terms of the values after dehydration. Since in both the wet and the dry conditions $l = b/\sin\theta$, (1) and (2) may be written

$$h_2^2 = b_2^2(1+x)^2/(1+y)^2\sin^2\theta_1 - b_2^2,$$

$$h_1^2 = b_2^2(1+x)^2/\sin^2\theta_1 - b_2^2(1+x)^2,$$

whence

$$\left(\frac{h_2}{h_1}\right)^2 = \frac{(1+x)^2/(1+y)^2 - \sin^2\theta_1}{(1+x)^2(1-\sin^2\theta_1)}. \tag{3}$$



(*a*) (*b*)

FIG. 1. Diagrammatic representation of part of an elongated cell cut open longitudinally and laid out flat. *Thick lines*—normal cell; *thin lines*—cell after dehydration. The oblique line in each case making an angle θ with the longitudinal represents one complete turn of the spiral, so that the length of cell illustrated corresponds to its pitch.

(*a*) With the spiral winding constant in length the inclination of the spiral decreases but its length increases. (*b*) If the length of the spiral winding decreases also on dehydration, the inclination still decreases, but cell length may also decrease.

h_2/h_1 may therefore be less than, equal to, or greater than unity according to the values of x, y, and θ. For the case in which $h_2/h_1 = 1$ we have from (3)

$$\sin^2\theta_1 = \frac{(1+x)^2(1+y)^2 - (1+x)^2}{(1+x)^2(1+y)^2 - (1+y)^2}. \tag{4}$$

For any given value of x and y, i.e. for any observed values for the relative contractions of the girth of a cell and of its spiral winding, an angle θ_1 may be determined for which the length of a cell corresponding to one complete turn of the spiral will remain constant during dehydration. If the inclination is less than this value, the length per turn will become less. Provided that the number of turns

of the spiral remains constant, this condition also applies to the whole length of the cell, and since very little sign of twisting was observed in the present material either during dehydration or the subsequent wetting out, we may assume this to be the case when dealing with the present results. It is to be noted that if x and θ_1 are known, a value for y may be calculated to fit equation (4). This is, of course, no substitute for a direct measurement of y, but, until a method has been developed to allow such a direct determination (and this will obviously be a matter of considerable difficulty) we have no alternative. Subsequent tests over the whole range of material will, as a matter of fact, provide a check on the value of y and a stringent test of the whole theory.

The results as presented in Tables I and II, though not as numerous as might be desired, are still too unwieldy to be used as a determinant of the critical angle θ_1, and must be grouped before analysis. The justification for grouping will be clear from the smooth run of subsequent figures. In Tables III and IV this grouping has been done, and it will be noticed that the classes into which the observations are grouped are not regular, as they would be, for instance, in a table made for strict statistical purposes, but are the classes into which the results presented in the first two tables happen by chance to fall. It becomes clear from this new arrangement of the data that for the hardwoods as a whole the micellar inclination giving no change of cell length on dehydration is in the neighbourhood of 39°, and from this value of θ_1, together with the value $x = 0{\cdot}13$, we may calculate y as 0·046 from equation (4). This gives us the relative contraction of the spiral winding in hardwood fibres and appears unexpectedly high. The corresponding figure from the softwoods (calculated from $\theta = 40°$, $x = 0{\cdot}18$) is 0·063. In this latter case we might expect the value for y to be high since it is known that the cellulose chains in the conifer tracheide are dispersed through a considerable angle (24), and the same is also therefore apparently true for the hardwood fibres.

The whole theory can now be tested by inserting the appropriate values in equation (3) for each inclination class in hardwoods and softwoods. In columns 4, Tables III and IV, are presented the observed values for h_2/h_1, and in columns 5 the corresponding calculated values. In both cases the agreement is definitely good considering the few observations which fall into each class. Towards the upper end of the inclination scale in both groups, and towards the lower end also with the softwoods, changes in length certainly tend to be smaller than might be expected from the theory here put forward, but possible explanations of this are immediately obvious. The determined value of θ_1 refers to each group as a whole and not to individual cells. There may obviously be some variation of θ_1 (brought about by variation in y) among individual cells, and we should therefore expect results to be somewhat uncertain in classes which contain small numbers of observations. Yet although this argument may hold in the classes of lowest inclination, it is always a feature of the highest inclination classes that dehydration does not involve any change in length. Measurements have been made on cells with inclinations of 60° and more and the values of h_2/h_1 has been found always to be unity. These figures are not included in the tables for reasons of space. It may be said quite definitely that the equations appear to hold with cells up to

TABLE III. *Hardwoods*

Source of fibre	*Number in sample*	*Inclination of m.e.p.*	b_2/b_1 (*obs.*)	b_2/b_1 (*calc.*)	$\frac{t_1-t_2}{t_2 x}$
Ash	3	21·3	0·970	0·967	0·922
Ash	2	23·2	0·972	0·969	..
Sycamore, Ash	2	28·3	0·945	0·976	0·861
Sycamore, Lime, Ash	3	31·4	0·985	0·981	..
Ash, Elm	2	32·9	0·986	0·987	0·789
Sycamore, Lime, Elm	4	35·9	0·974	0·992	..
Sycamore, Lime	2	38·2	0·988	0·998	..
Lime, Elm	3	39·3	1·000	1·002	0·700
Sycamore, Ash, Elm	4	40·6	1·011	1·011	..
Sycamore, Lime	2	45·4	1·000	1·050	0·411

TABLE IV. *Softwoods*

Source of tracheide	*Number in sample*	*Inclination of m.e.p.*	b_2/b_1 (*obs.*)	b_2/b_1 (*calc.*)	$\frac{t_1-t_2}{t_2 x}$
Cypress	1	23·7	0·972	0·957	0·889
Cypress	2	27·6	0·990	0·964	..
Cypress, Yew	3	32·5	0·976	0·974	..
Pine, Yew, Cypress	3	34·8	0·986	0·980	0·705
Cypress, Yew, Cedar	7	37·7	0·994	0·990	..
Cedar, Yew	3	40·0	0·998	1·000	0·611
Cypress, Pine	4	43·3	1·002	1·016	0·500
Cedar.	1	54·0*	1·000	1·096	0·072

* Intermediate classes are omitted since b_2/b_1 is equal to unity.

inclinations of 40°, after which some secondary mechanism takes charge, preventing any length change. A possible source of this restricting agency is not far to seek. Hitherto we have considered only the radial contraction of the cell leading to a decreased girth. Together with this, however, goes a tangential contraction so that the windings of the spiral tend to approach each other, i.e. t_2, Fig. 1 (*b*), must decrease as b_2 decreases, and the nature of the cellulose matrix demands that the relative decrease in these dimensions must be of the same order. On the present theory we may calculate what the relative decrease of t_2 must be, in view of the geometry of the spiral, for each of the inclination classes assuming a girth contraction of 0·18 for softwoods and 0·13 for hardwoods. It is preferable to express this in terms of the decrease in b thus:

$$\frac{t_1-t_2}{t_2 x} = \frac{b_1 \sin\theta_1 - b_2 \sin\theta_2}{b_2 \sin\theta_2 x}$$

$$= \frac{\frac{b_2 b_1}{K l_1} - \frac{b_2 b_2}{l_2}}{\frac{b_2 b_2 x}{l_2}}$$

$$= \frac{1}{x}\left(\frac{1}{K}\frac{1+x}{1+y} - 1\right),$$

where θ_1, θ_2 are the inclinations of the cells in the wet and dry conditions respectively and $K = b_2/b_1$. The calculated values are given graphically in Fig. 2 and in column 5, Tables III and IV. They may be regarded as the resultant of the large transverse contraction and the small longitudinal contraction, dependent on the spiral organization of the wall and the inclination of the micelles in the spiral. In other words, the geometry of the spiral imposes a restriction on contraction in a direction at right angles to the spiral winding in the plane of the wall surface. Now if we imagine part of the wall dissected out, then this isolated piece of wall, in consequence of the structure of its cellulose complex, would contract in the radial and the '*t*' direction very much to the same extent, the precise value of each contraction depending on the condition of the cellulose with regard to angular dispersion. In the intact cell the contraction in the '*t*' direction is a compromise between this 'natural' contraction and that imposed upon it by the nature of the spiral. Thus it seems that in the wall the relative contraction $(t_1-t_2)/t_2$ can assume a value varying from at least $0{\cdot}9x$ to $0{\cdot}4x$ in hardwoods. If the inclination of the spiral is greater than about 40°, then the configuration of the spiral implies a relative contraction in t much less than the contraction natural to the cellulose. The actual contraction which occurs, therefore, greater than the contraction demanded if the spiral is to behave according to the present theory, tends to reduce the cell extension which would otherwise occur. At the lower limit of the inclination scale in softwoods, on the other hand, the contraction demanded by the spiral may be so much greater than the 'natural contraction' that this latter again assumes control. This would suggest that the 'natural' contraction in the '*t*' direction lies between the limits given above, i.e. $0{\cdot}9x$ to $0{\cdot}4x$, and that

therefore the angular dispersion of the micelles is greater about a line normal to the wall surface than about a line tangential to the surface and at right angles to the winding.

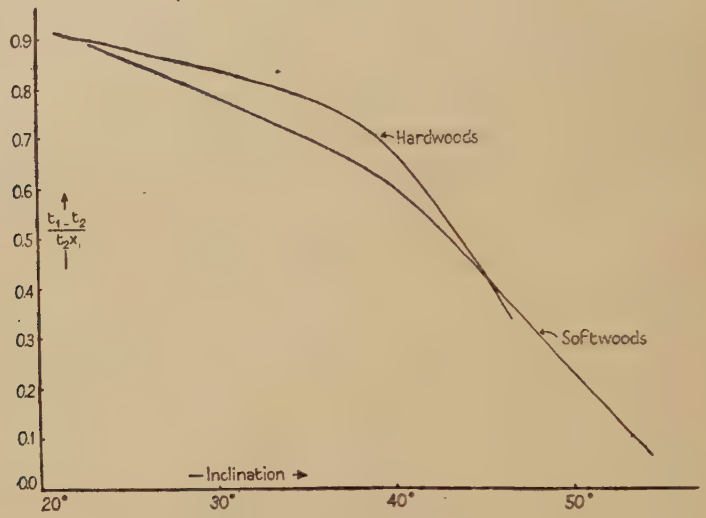


FIG. 2. For explanation, see text.

Finally, it is to be noted that the percentage recovery observed when the cells are replaced in water is, on the whole, less for cells with steeper spirals than for those with flatter spirals. This again is understandable, since the former have undergone the greater contraction in alcohol. It may well be that the adjustments which must take place between the 'natural' contraction of t and that imposed on it by the spiral are irreversible.

Individual plant cells thus differ from compound structures such as rope in that the latter, though composed of plant cells, always elongate on dehydration. This difference is to be explained in terms of the structure of the rope. The individual yarns of which rope is composed consist of fibres twisted in the yarn at a considerable angle to its length. These fibres themselves (which thus constitute the spiral winding of the yarn) always contract in length on drying, since their cellulose chains are arranged almost longitudinally. Therefore, on the present line of argument, the length contraction of the yarn will be much less than that of the individual fibres and may be zero or even negative. It is, as a matter of fact, difficult to demonstrate any length change of rope yarn on drying. Since now the yarn itself is wrapped in a spiral to form the rope, the whole structure will elongate on drying, as indicated in Fig. 1 (*a*).

(*b*) *The Anisotropic Contraction of Wood and its Bearing on Stresses and Strains in Growing Timber.*

(1) *Anisotropic Contraction.* The contraction in length of cells on drying is thus much smaller than the contraction in girth, and this is clearly associated with the

swelling properties of the cellulose complex and with the direction of the cellulose chains in the wall. Similarly, the contraction in length of wood parallel to the grain is relatively small and it seems not unreasonable to connect the two. It is proposed here to examine the problem of anisotropic contraction of wood in the light of the argument presented above and for the present to confine attention to the more uniformly constructed wood of conifers.

Some attempt has already been made to explain the smallness of length contraction in pieces of wood in terms of the micellar inclination of their constituent cells. Thus Vintila (30), constructing a vector diagram for the transverse contraction α_t and the longitudinal contraction α_l (Fig. 3), determined the resultant contraction α_m which he assumed to be at right angles to the direction of the cellulose chains in the wall. This type of diagram has actually no theoretical basis, as was pointed out by Frey-Wyssling (9), and, as the latter author shows and as appears also in the later work of Turnbull (29), to which a similar criticism applies, gives values of the micellar inclination far smaller than those actually

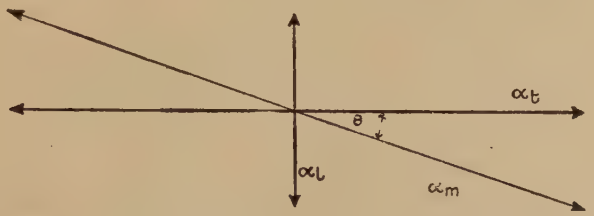


FIG. 3. Vector diagram of the components of swelling in wood. For explanation, see text.

observed by the present writer (22). Frey-Wyssling points out further that, as already mentioned in the present paper, transverse contraction of a spiral the length of whose winding remains constant always implies longitudinal *extension*, whereas longitudinal *contraction* invariably appears in wood. On these grounds Frey-Wyssling, in spite of an earlier attempt to explain anisotropic contraction in the transverse plane (8) in terms of the determinations of micellar inclination carried out by the writer (22), rejects the cell wall as a controlling factor and attributes anisotropic contraction to the properties of the middle lamella. This seems quite unjustifiable in view of the statement, as made in a paper in which Frey-Wyssling was joint author (13) and supported in the present research, that the spiral winding can actually contract on dehydration. If we take this contraction into account, we see that individual cells do contract in theory almost exactly as they are observed to do, and that the longitudinal contraction is small. In actual fact, the observed longitudinal contraction of wood is of the same order as the contraction observed here in individual cells. Thus Vintila (30) gives figures for the longitudinal contraction in the early wood of larch and fir from which we may calculate h_2/h_1 as 0·997 and 0·998 respectively, and the mean of 154 determinations by Turnbull (29) on *Pinus patula* yields a figure of the same order. In terms of the figures given in Table IV this implies a 'mean' micellar inclination of some 39° in each case. This is well within the range of inclinations

known to occur in conifers and not far removed from the averages observed directly (22). It is particularly to be noted that since tracheides contribute nothing directly to length changes, if their inclinations are greater than 40°, then the contraction observed on wood in bulk should be controlled by tracheides whose micellar spiral is steeper than this. The 'average' inclination determined from contraction studies must therefore be less than the true mean value. This appears in practice to be true, for the average inclinations in larch and fir as determined under the polarizing microscope are 44° and 48·8° respectively (seventh annual ring). It may perhaps further be mentioned in passing that some of the otherwise inexplicable results of Turnbull (29) also harmonize with the present theory. Turnbull determines the ratio α between the longitudinal percentage shrinking and the transverse percentage shrinking. He finds that this ratio has strong negative correlation with transverse shrinkage. If this is not merely a consequence of the presence of the latter property as denominator in the ratio, it can be explained along the present lines since increase in x causes an increase in the tendency of the spiral to elongate on dehydration, as shown by the formulae presented above. Increased transverse shrinkage thus means a decreased longitudinal shrinkage and therefore a lower ratio α. In addition to this, an increase in x may clearly, on the present theory, be attributed to a decreased angular dispersion of the cellulose chains in the wall and therefore a decreased value of y leading to a lower contraction in the tissue as a whole. Similarly, the fact that α is greater in drying from green to oven-dry than it is in drying to the air-dry condition surely arises as a consequence of the fact that the cellulose complex has numerous fine capillary spaces parallel to the cellulose chains. On drying, the water in these capillaries will evaporate first, giving a large value of x, the transverse contraction, and a small value of y with therefore a small longitudinal contraction and a low value of the ratio α. Only when the material is oven-dried will the water in the finest capillaries and some of the adsorbed water be evaporated, and it is clearly only at this stage that the value of y and therefore ultimately the ratio α will be large.

There thus seems good grounds for the conception that the fine structure of the tracheide wall is responsible for the anisotropic contraction of the wood of softwood trees when length changes are compared with transverse changes in dimension. Even when the anisotropy observed on transverse sections is considered, we are tempted to make the same generalization as Frey-Wyssling did in his earlier paper (8). It is, however, rather difficult to see how the wall is concerned with anisotropy in this transverse plane. If the individual tracheide contracts, for instance, 18 per cent. in diameter it must also contract 18 per cent. in circumference whatever the inclination of its constituent micelles. Although we know that the inclination of the micelles on radial walls of tracheides is greater than on tangential walls (22), it is not easy to connect this difference with difference of contraction. Nor is it any easier to see how the difference in number of cells per unit length along a radius and along a tangent can effect anisotropy, in spite of the striking comparisons made by Frey-Wyssling (9) between this difference and anisotropy for a number of different woods; for if each cell increases in diameter, say, 18 per cent., then a file of cells, side by side, will also increase in

breadth 18 per cent. however many cells are present per unit length. Until further research is carried out on this aspect of the problem it seems safer to go back to the original suggestion of Clarke (3) that the anisotropic contraction in the transverse plane is associated with the type and distribution of the ray system.

(2) *Stresses and Strains in Timber.* If the above interpretation is correct, then the longitudinal contraction of wood is to be thought of as controlled largely by the nature and arrangement of the micellar spirals of its constituent cells, and it follows as a necessity that the contraction in different regions of the wood should vary as the inclination of the spiral varies. Such differential contractions on drying would then inevitably lead to tensions on the wood, and these tensions should be associated with *changes* of micellar inclination along the line of tension gradient.

In recent years attention has been called by Martley (18) and, with greater force, by Jacobs (14, 15 (see also Clarke (4)), to the presence in normal timber of longitudinal tensions in the outer woody layers of a tree, though not usually associated with drying as such. Jacobs in particular has produced sound evidence, based on the pronounced curvature of strips cut out from the tree, that these tensions exist sufficiently great to induce longitudinal compression of the heartwood and to split planks cut radially from the tree. He suggests, again on the most convincing evidence, that this tension arises from the fact that each consecutive sheet of wood is laid down under slight longitudinal tension and that the progressive laying down of more and more layers of wood gives rise to a cumulative longitudinal compression of the woody cylinder. As the wood elements differentiate from the cambium, Jacobs considers them to shrink slightly and the resistance to slip afforded by the adhesion to the woody cylinder on which they are laid results in the development of tension. The evidence shows that in general this tension increases from zero at a point where the outer tension and the inner compression are in dynamic balance to a maximum towards the outer rings of the tree. While most of Jacobs's work was carried out on *Eucalyptus*, a hardwood, he also observes similar phenomena in softwoods. Now we know enough about softwood structure to make a rough comparison of the tension distribution with the variation in wall structure from one annual ring to the next. In the first annual ring, for instance, the following figures have been recorded:

Species	*Inclination on radial walls*		*Inclination on tangential walls*	
	Range	*Average*	*Range*	*Average*
Cedrus	36·0–67·0	56·0 1·0	31·0–57·8	42·8 1·0
Larix A	40·0–71·0	56·0 1·0	32·6–55·2	45·9 1·0
Larix B	32·0–71·0	56·0 1·0	25·0–49·0	35·6 1·0
Abies	42·8–68·8	53·3 1·0	.. ..	.. ..
Pinus longifolia	44·0–78·5	58·7 1·0	24·0–64·0	46·3 1·5

The last species is taken from Misra (20) and showed spiral grain. The difference in inclination between radial and tangential walls is maintained for a number of

years, but is reduced by a progressive decrease, year by year, in the inclination on radial walls until by the end of the seventh year of growth it has fallen approximately to the level of that on tangential walls. Remembering that in general tracheides with inclinations less than 40° contract in length on drying, while those with inclinations above this either elongate slightly or show no change at all, we see that if the woody elements are considered to 'dry' slightly as they differentiate, then outer annual rings will contract more than inner rings and lead therefore to tensions. This connexion between inclination and tension is particularly marked in *Pinus longifolia*, where the inclination falls both on radial and tangential walls to about 25° in the sixth annual ring. In the other species studied, although the inclination does not fall below 40° (average) in the rings observed, nevertheless the wide range of inclination in any ring ensures a contraction of the woods as a whole. The contractions observed by Jacobs in strips removed from the tree are of the general order $h_2/h_1 = 0{\cdot}999$, and thus fall well within the range studied here.

It is thus possible to attribute the development of longitudinal tension in wood to what we may call 'deswelling', corresponding in effect to slight dehydration. Münch (21), on the other hand, has connected the development of tensions in the 'Weissholz' of conifers with a *swelling* of the developing tracheides on the assumption that the length of the micellar spiral winding remains constant. There is little direct evidence for the swelling proposed by Münch or for the 'deswelling' discussed here, but the balance of indirect evidence at the moment favours the latter point of view. Thus, actual experiment shows that tracheides contract in length on drying, not on wetting, and the same is true of wood as a whole. If therefore tensions come about by longitudinal contraction, this contraction must be caused by 'deswelling'. Again, we have further evidence from the cell wall itself. In a number of cell walls (*Valonia* (26), *Cladophora* (2)) certain planes in the molecular structure tend to lie parallel to the wall surface. In bacterial cellulose, however, the same is true only after the plate of cellulose has been dehydrated (28). It seems therefore likely that in the algae mentioned above the wall has undergone slight dehydration during development. The size of tracheides makes it impossible at the moment to establish the same facts for their walls but, though it seems rather a far cry from tracheides to algal cells, our knowledge of the identity of cellulose in a number of types chosen from various orders in the Plant Kingdom (10, 11) and even in the Animal Kingdom (19) leads us to imagine that similar conditions will apply in tracheides as in algal cells. We have again then some evidence in favour of 'deswelling', and further work on tracheides from this point of view might clinch the matter.

Lack of adequate data makes it undesirable to pursue this study into the properties of 'reaction' wood, but it should be pointed out that the condition of wood of this type may eventually be understood from the present viewpoint. An attempt has already been made by Münch (21) to correlate the features of reaction wood with the structure of its constituent cells. He bases his argument on the supposition that the walls of the elongated cells of the type under consideration are wound with at least two spirals: an outer, flat spiral, an inner steep

spiral and, occasionally, an innermost spiral which is again flat. There is no question about the existence of the steep spiral, for this has been demonstrated by an X-ray method (22). X-ray analysis shows further that if any other spiral exists in the wall, then it is present in a layer too tenuous to produce diffraction spots on the photograph, and optical determinations (24) lead us to suspect that such a layer is, in fact, absent. The observation of outer flat 'striations' on the tracheide wall, used by Münch as evidence of transversely oriented cellulose micelles, loses much of its force in view of the fact that similar transverse markings can be induced even by slight swelling in fibres (17, 25), and are folds in an outer layer induced by differential swelling bearing therefore no relation to the underlying molecular structure. The only strict comparison made, as far as the present writer is aware, between the micellar structure of pressure and of tension wood shows in any case that the inclination of the micelles is about the same in the two classes of wood (13), so that the greater longitudinal shrinkage of pressure wood on drying (21) is to be sought in some other property of the spiral. This is possibly the angular dispersion of the micelles in the spiral winding exercising its influence through the value of y.

Thus from relatively simple considerations it is possible to derive an explanation of the commercially important property of anisotropic shrinkage of normal wood in terms of the precise nature of its cellulose complex, and it seems not impossible that an understanding of reaction wood may be reached along similar lines. The writer finds himself in complete agreement with Clarke (5) concerning the importance of wall studies in the elucidation of problems connected with timber; it is imperative that more attention be paid to the structural details of the cells constituting timber than appears to have been given hitherto. It is high time that wall studies ceased to be of academic importance only and began to take their place in wood technology.

SUMMARY.

As a result of observation of cell dimensions and wall structure in fibres of hardwoods and tracheides of softwoods, it appears that the anisotropic shrinkage of these cells on drying arises as a consequence of the anisotropic properties of their cellulose complex. A theoretical discussion is presented, admittedly in a very simple form, of the connexion between swelling behaviour of cellulose and of whole cells, and the experimental observations are found to agree closely with predictions. It therefore follows that anisotropic shrinkage in wood in bulk may also be connected with the properties of the cellulose complex, expressed in terms of the cell types composing the wood. As far as the data now available are concerned longitudinal shrinkage in wood appears to be of the same order as that observed here in single cells; and further yields a figure for the average micellar inclination of the constituent cells very close to that determined by direct observation. Various other features of anisotropic shrinkage of wood prove also to be in harmony with the present theory. Finally, it appears that the development of stresses in growing timber may not be unconnected with the swelling properties of its constituent cells, following the lines of the present theory.

LITERATURE REFERENCES.

(1) Anderson, D. B.: *Bot. Rev.* i. 52, 1935.
(2) Astbury, W. T., and Preston, R. D.: *Proc. Roy. Soc.* B 129, 54, 1940.
(3) Clarke, S. H.: *Forestry*, iv. 93, 1930.
(4) —— Ibid. xiii. 68, 1939.
(5) —— *Forestry Abstr.* Vol. i, No. 2.
(6) Frey-Wyssling, A.: *Die Stoffausscheidung der Höheren Pflanzen.* Berlin, 1935.
(7) —— *Naturwiss.* xxviii. 385, 1940.
(8) —— *Holz als Roh- und Werkstoff*, iii. 43, 1940.
(9) —— Ibid. iii. 349, 1940.
(10) Harlow, W. M., and Wise, L. F.: *Am. Journ. Bot.* xxv. 217, 1938.
(11) —— —— Ibid. xxv. 760, 1938.
(12) v. Höhnel: *Ber. dtsch. bot. Ges.* xli, 1884.
(13) Jaccard, P., and Frey, A.: *Jahrb. wiss. Bot.* lxviii. 844, 1928.
(14) Jacobs, M. R.: *Australia Commonwealth For. Bur. Bull.* 22, 1938.
(15) —— Ibid., 1939.
(16) Kundu, B. C., and Preston, R. D.: *Proc. Roy. Soc.* B 128, 214, 1940.
(17) Majumdar, G. P., and Preston, R. D.: *Proc. Roy. Soc.* B 130, 201, 1941.
(18) Martley, J. F.: *Forestry*, ii. 69, 1928.
(19) Meyer, K. H., and Mark, H.: *Der Aufbau der Hochpolymeren organischen Naturstoffe.* Leipzig, 1930.
(20) Misra, P.: *Forestry*, xiii. 118, 1939.
(21) Münch, E.: *Flora*, N.F. xxxii. 357, 1937–8.
(22) Preston, R. D.: *Phil. Trans.* B 224, 131, 1934.
(23) —— *Biol. Rev.* xiv. 281, 1939.
(24) —— *Proc. Leeds Phil. Soc.* Sci. Sec. iii. 546, 1939.
(25) —— and Astbury, W. T.: *Proc. Roy. Soc.* B 127, 76, 1937.
(26) —— *Proc. Roy. Soc.* B 130, 103, 1941.
(27) Seifriz, W.: *Protoplasma*, xxi. 129, 1934.
(28) Sisson, W. A.: *Journ. Phys. Chem.* xl. 343, 1936.
(29) Turnbull, J. M.: *Journ. South African For. Assoc.* v. 62, 1940.
(30) Vintila, E.: *Holz als Roh- und Werkstoff*, ii. 345, 1939.

THE VARIABILITY IN RESISTANCE TO DECAY OF THE HEARTWOOD OF HOME-GROWN EUROPEAN LARCH, *LARIX DECIDUA*, MILL. (*L. EUROPAEA*) AND ITS RELATION TO POSITION IN THE LOG

BY K. ST. G. CARTWRIGHT

(*Forest Products Research Laboratory*)

INTRODUCTION.

IN 1940–1 I investigated the variability in resistance to decay of the heartwood of Western red cedar (*Thuja plicata* D. Don.) (1). The significant results obtained suggest that results of similar experiments on other timbers, including both durable and less durable species, might, when considered together, throw light on the reasons for the varying resistance shown by different samples of the same species and so partly explain the varying behaviour of timber in service when exposed to conditions favourable to fungus attack.

The wood of Western red cedar is known to contain an extractive toxic to wood-destroying fungi, and, therefore, the significant results obtained were not unexpected. In this investigation European larch has been selected, a timber which though resistant to fungus attack cannot be classed as very resistant and is not known to contain an extractive highly toxic to fungi.

The tree, which was obtained from the Hampden House Estate, Great Missenden, Bucks., was about 95 years old, and the heartwood at the base was 16 inches in diameter. The rate of growth varied, but averaged about 10 rings per inch. The clear bole from which the test samples were obtained was about 45 feet in height.

CONVERSION AND SELECTION OF SAMPLES.

From the clear bole 3 disks were cut, the first at the butt, the others at 20 feet and 40 feet respectively. From each disk a section was cut which included the central core, but from which the sapwood was removed. Test samples were obtained from these three sections, the method of conversion and size of these being identical with those described in the previous investigation on Western red cedar (2).

SELECTION OF FUNGI.

Three species of fungi were chosen as test organisms, namely:

1. *Polyporus Schweinitzii* Fr., which causes a brown cubical rot of standing conifers.
2. *Poria xantha* Lind., which causes a brown cubical rot of felled conifers and is a frequent cause of decay in the woodwork of greenhouses.
3. *Fomes annosus* Fr., which causes a white pocket rot of standing conifers.

Cultures of these fungi were prepared in flasks, the medium being Norway

spruce sawdust with the addition of an accelerator (1), and when the fungi had grown vigorously throughout the medium, the test samples, after oven-drying and weighing, were placed in the flasks and exposed to fungus attack, the technique followed being similar to that of the previous investigation.

The test samples were removed in the case of *P. Schweinitzii* after 4 months, and after 2 months and 8 months for *Poria xantha* and for *Fomes annosus* respectively, the period of exposure chosen for each fungus being based on previous work in order to ensure a significant loss of weight in the test sample.

After removal from the flasks the samples were oven-dried and the loss in weight for each sample calculated as a percentage of the original dry weight.

RESULTS.

In the table below the percentage loss in weight is given for each group of samples. The number of samples from which each figure was obtained is put in brackets. The variability in number of samples was due to the necessity for rejection of any sample which showed any abnormality such as resin pockets, knots, &c.

Position of Disk	*Heartwood*	*Polyporus Schweinitzii* — *Per cent. loss in weight based on oven-dry weight*	*Poria xantha* — *Per cent. loss in weight based on oven-dry weight*	*Fomes annosus* — *Per cent. loss in weight based on oven-dry weight*
Base	Adjacent to sap	8·70 (24)*	14·8 (8)	2·9 (4)
	Adjacent to pith	13·4 (20)	26·1 (12)	4·3 (4)
20 ft.	Adjacent to sap	..	23·1 (7)	5·9 (4)
	Adjacent to pith	..	16·7 (8)	9·1 (3)
40 ft.	Adjacent to sap	..	17·9 (8)	5·6 (8)
	Adjacent to pith	..	20·3 (8)	8·3 (3)

Duration of test for *P. Schweinitzii*, 4 months; for *P. xantha*, 2 months; and for *F. annosus*, 8 months.

* Numbers in brackets indicate number of samples upon which the figure for average percentage loss in weight was calculated.

DISCUSSION OF RESULTS.

In the butt section considerably higher losses in weight were brought about in those samples taken adjacent to the pith than from those near the sapwood, thus agreeing with the results obtained for Western red cedar.

Samples taken at a height of 20 feet from the base gave reverse results with *Poria xantha*, the least resistant timber being that adjacent to the sapwood, but at 40 feet the heartwood next to the sapwood showed greater resistance than that next the pith. At present it is impossible to explain this reversal of the

position at 20 feet, and a further investigation is required before this can usefully be attempted. There was no evidence of any significant progressive variation in degree of resistance in timber taken from the base from that higher up, except that wood taken from the base was on the whole the most durable. Within the basal section wood adjacent to the sapwood is significantly more resistant than that adjacent to the pith. Test samples from half-way between the outer and innermost heart gave intermediate losses in weight as a result of decay, indicating that the increase in resistance from the centre outwards towards the sapwood is a progressive one. This suggests that the variation in resistance may be associated with variations in the concentration of extractive as was found to be the case in Western red cedar. These results strengthen the suggestion made in the previous paper that the form taken by heart rots in living trees may be due not only to infection having entered through dead tap roots, but also because this central core may in many species be more vulnerable to fungus attack owing to the absence of sufficiently high concentrations of extractives containing substances which inhibit fungus attack.

ACKNOWLEDGEMENT.

The work described above was carried out as part of the programme of the Forest Products Research Board and is published by permission of the Department of Scientific and Industrial Research.

LITERATURE REFERENCES.

(1) Cartwright, K. St. G.: 'The Variability in Resistance to Decay of the Heartwood of Home-grown Western Red Cedar, *Thuja plicata* D. Don. and its Relation to Position in the Log.' *Forestry*, 1941, xv. 65–75.

(2) Badcock, E. C.: 'New Methods for the Cultivation of Wood-rotting Fungi.' *Trans. Brit. Mycol. Soc.*, 1941, xxv, Pt. II, 200–5.

THE NUMBER OF SAMPLE TREES REQUIRED FOR DETERMINING VOLUMES OF WOODS WITH VARIOUS DEGREES OF ACCURACY

BY REGINALD DAVEY

INTRODUCTION.

LARGE woods are generally measured by the method of the 'Mean Basal Area Tree'. It has become established by long usage, in spite of adverse criticism [(1) 55]. In its simplest form it consists of measuring and tabulating the breast-height girths of all the trees in the wood, and calculating the total basal area. This, divided by the number of trees, gives the basal area of the average tree, the quarter girth of which is looked up in tables. A number, usually 20, trees possessing this girth are measured standing, and their average volume taken as that of the mean volume tree. A number of refinements, by dividing the trees into groups, have been introduced from time to time. These aim at increasing the accuracy of the estimate. The method of selecting the sample trees has also been considered, resulting in two modifications of the principle of the random sample. The Forestry Commission research staff select as sample trees those that appear typical of the stand [(2) 10 and (3) 124]. The difficulty of choosing trees possessing mean values led Chaturvedi to propose the selection of an equal number of maximum and minimum trees [(1) 42]. Neither of these methods enable a determination of the probable accuracy of the resulting volume. In the case of a random sample, in which the trees are selected by a purely mechanical method, both the probable accuracy of the result and the number of trees required for a given standard of accuracy can be determined. The calculations are the same, whether the mean basal area tree method is used or the new system of separate means proposed by Chaturvedi [(1) 59], and developed elsewhere (4) for commercial measurement. Sampling errors are due primarily to the scatter of the various dimensions of individual trees about the mean. The ordinary process of measuring standing trees introduces a secondary source of error, which can with care be kept within modest limits.

ERRORS OF MEASUREMENT (based on assumptions and not on calculated statistics).

The breast-height girth of each sample tree is measured with a tape. The liability to error is small, compared with height and taper, and it can safely be neglected. If an instrument is used for tall trees, it may be considered reasonable to anticipate an accuracy of 5 per cent. when measuring the height of a growing tree. This means that a 40-foot hardwood is measured within a foot twice in every three trials, and within 2 feet 21 times in 22 trials. An 80-foot conifer requires measuring within 2 and 4 feet respectively in the same numbers of trials. This is expressed as follows:

Standard error of measuring height $= \pm 2{\cdot}5$ per cent.

Height can be measured, but taper must be estimated. For this reason an accuracy of 10 per cent. is proposed.

Standard error of estimating taper = ±5·0 per cent.

The influence of the new taper tables (4) on the accuracy of estimation can be judged only after trial by different persons under varying conditions.

Both these errors of measurement are present in the resulting volume, and they are combined by the formula for the standard error of a product.

Standard error of determining the volume of a growing tree = ±5·6 per cent.

This represents the assumed error due to measuring a tree standing. It does not arise in the case of felled trees. It is additional to errors of sampling due to the scatter of the individual measurements.

SCATTER OF TAPER×HEIGHT.

Height and taper are multiplied together in order to obtain the volume. The error due to their respective dispersions can be determined separately for each, and then combined by the formula for the standard error of a product. Alternatively the taper×height of each stand may be considered. Both methods yield the same result.

In order to obtain an indication of the general magnitudes involved the following trees were measured on the ground from plantations in Sussex and Oxfordshire: 162 hardwoods; 141 conifers, over 8 inches quarter girth, at 5 feet; 119 conifers, under 8¼ inches.

The standard deviation of the taper×height of each sample was determined and expressed as a percentage of the mean. The standard deviation of the standard deviations was also calculated. The following statistics emerged.

Standard deviation of taper×height

	No. of stands	*Standard deviation, per cent. of mean*	*Maximum value*
Hardwoods . . .	6	±18 per cent.±3·6	±25 per cent.
Conifers, over 8 in. . .	7	15 per cent.±2·4	20 per cent.
„ under 8¼ in. .	3	18 per cent.±2·9	24 per cent.

The maximum value of the standard deviation likely to be found in practice is taken as the standard deviation of the means plus twice the standard deviation of the standard deviations. There is, on the basis of the present data, a 21 to 1 chance that it will not be exceeded. When trees are measured standing, the standard deviations are increased by the errors of measurement. These are represented by a standard error of ±5·6 per cent. (see previous section). Using the formula for the standard error of a product, the standard deviations of taper×height assume the following values.

Standard deviation of taper×height of sample trees measured standing

	No. of stands	*Standard deviation, per cent. of mean*	*Maximum value*
Hardwoods . . .	6	±19 per cent.±3·8	±26½ per cent.
Conifers, over 8 in. . .	7	16 per cent.±2·6	21 per cent.
„ under 8¼ in. .	3	19 per cent.±3·1	25 per cent.

Substituting the maximum values of the standard deviation in the formula for the standard error of a mean provides the number of standing sample trees required for a given accuracy.

Number of sample trees, measured standing, required to determine the total volume of a wood within the following degrees of accuracy

	Probable accuracy	
	21 : 1 chance of 6 per cent.	*21 : 1 chance of 8 per cent.*
Hardwoods . . .	78	44
Conifers, over 8 in. . .	49	28
„ under 8¼ in. .	70	39

This table provides for the maximum scatter of the values that the data indicates as probable, on the basis of a 21 to 1 chance. In the majority of cases the numbers of trees indicated can be relied upon to yield a higher degree of accuracy, provided care is bestowed upon the measurement.

In this connexion it is interesting to consider the probable accuracy of the volume based on a sample of 20 trees measured in each of the 18 stands, 16 of which were used for the purposes of these calculations.

Probable accuracy (21 : 1 chance)	*No. of stands*
5 per cent.	2
6 „	4
7 „	5
8 „	3
9 „	2
10 „	1
11 „	1
	18

The trees were measured on the ground, so that no account is taken of the error in measuring growing trees.

SUMMARY.

Little attention has been paid to the numbers of sample trees required for a given standard of accuracy. In order to investigate the question 422 trees from 16 plantations in the south of England were measured on the ground. These enabled the determination of the probable scatter of taper × height.

The resulting statistics, combined with assumed errors of measurement of standing trees, provided an indication of the general magnitude of the maximum standard deviations likely to be found in practice.

The numbers of sample trees required for a 21 to 1 chance of a total volume within 6 per cent. and 8 per cent. of the true volume were determined for hardwoods and conifers.

LITERATURE REFERENCES.

(1) Chaturvedi, M. D.: *Measurement of the Cubical Contents of Forest Crops.* Oxford University Memoir No. 4 of 1926.

(2) Forestry Commission. *Growth and Yield of Conifers in Great Britain.* 1928. Bulletin No. 10. H.M. Stationery Office.

(3) Macdonald, James: 'Form of Stem in Coniferous Trees.' *Forestry*, vii, No. 2, Dec. 1933.

(4) Davey, Reginald: *Measurement of Trees.* 1941. Forest Press, Nutley, Sussex.

SOCIETY'S AND OTHER NEWS

FINANCES

Under the war-time arrangements mentioned in volume xv the Council has approved the audited Abstract of Accounts of the General Fund for year 1941, which closed with balances of £206. 8*s*. at credit of Capital and £334. 8*s*. 4*d*. at credit of Revenue. The Council transferred £200 of the latter to Capital and invested it in 3 per cent. Defence Bonds in names of the trustees, and lodged a further £100 of the Revenue balance in Edinburgh Savings Bank in terms of Rule 10, where it is on loan to the Treasury. The balances of £22. 2*s*. at credit of the Medal Fund and £21. 15*s*. 11*d*. at credit of the Excursion Fund have also been lodged in the Savings Bank.

ANNOUNCEMENT

Tree Measurements

Timber measurers, in the ordinary course of their work, accumulate a vast body of data. By summarizing, a certain amount of useful local information is obtained. But its full value can be realized only by pooling the local data, and making it available, both in summary form and as tables of general application.

The 'Scheme for Pooling Tree Measurements', taking advantage of the present heavy rate of felling, makes provision for collecting data upon a mutual basis. Details may be obtained from Mr. Reginald Davey, M.Sc., Sandymount, Nutley, Sussex, England.

SOCIETY OF IRISH FORESTERS

The Society of Irish Foresters, modelled on our Society and having similar objects, was founded in Dublin on 21 September 1942. Dr. Mark L. Anderson, Director of Forestry in Eire, is its first President, with Mr. Felix McMahon, a working forester, as Vice-President. The Editor is Mr. M. O'Beirne, Inspector in charge of the training school, and the Secretary and Treasurer is Mr. Thomas Clear, Lecturer in Forestry, Albert Agricultural College, Glasnevin, Dublin.

OBITUARY

THE LATE FLIGHT-LIEUT. ALEXANDER NOEL DAVID

A. N. David, who died recently on service at the age of 53, was educated at Aldenham and Oxford, and began his career in the Indian Forest Service, which he joined in 1911, and served in Assam till 1916, when he entered the Royal Flying Corps as pilot, seeing service chiefly at Salonika, returning to India in 1919. He retired from the Indian Forest Service in 1922 and shortly after became associated with the beginnings of the Forest Products Research Laboratory, and worked at that laboratory until the outbreak of war, when he at once rejoined the R.A.F.V.R. Shortly before his death he received a mention in dispatches. His cheerful hard-working personality made him very popular with his colleagues in all the spheres he worked in, and made him a very useful liaison between the laboratory and the woodland owners with whom he frequently came in contact.

REVIEWS

Measurement of Trees. By Reginald Davey. Forest Press, Nutley, Sussex. 1942. Price 21*s*.

Review by James Macdonald

THIS is an interesting publication in which the author sets out, laudably, with the intention of improving the methods of forest mensuration as practised in this country. He tells us that his 'object is to simplify the measuring of trees and woods for sale, so that

the exercise of care can secure results at present attainable only after years of practice'. What the author really appears to aim at is not further simplifying of existing methods which are already about as simple as they can be, but the forging of a method for the use of valuers and estimators which will replace the guesswork, based usually on experience, but sometimes solely on optimism, which passes for volume determination at the present day.

Mr. Davey goes straight to the heart of the matter. If trees did not taper or if all trees tapered uniformly, then measurement would not present such a devil of a problem. This the author realizes, and one may regard the sections on taper as the central feature of his book, with its success depending on his treatment of this part of the subject.

There are one or two novelties, one of which is the definition of 'timber-point', the point to which one measures height on a standing tree and length on a felled tree. For conifers of pit-prop size convention is followed and the timber length is measured out to a diameter fixed at 3 inches. For conifers too large to be cut into pit-props the author proposes, instead of measuring as is customary to a fixed diameter, to take as his timber-point a place on the stem where the quarter girth is one-third of the quarter girth at 5 feet from the ground. In other words, he replaces a fixed top diameter by a variable one. I can see no advantage in this. On a felled tree an additional measurement (that at 5 feet) becomes necessary, thus increasing the work, while on a standing tree there is the added difficulty of estimating a girth at some distance above ground, a much more difficult job than guessing a diameter. The author contends that his new 'timber-point' has a closer relation to actual commercial uses, but is this indeed so? Commercial uses vary. What is saleable in the south of England may have to rot on the ground in the Scottish Highlands for lack of demand, and what cannot be used in peace may meet an eager demand in war. Mr. Davey realizes the difficulty of estimating a girth at some distance above ground and he provides a table giving for conifers of different species, ages, and sizes the timber-point as a percentage of total height. Total height in conifers can be measured with reasonable accuracy, and this method though open to some objection is better than simple guesswork.

In dealing with the taper of trees Mr. Davey has made use of certain work on the stem-form of conifers published in this journal some years ago, and has supplemented this with various data which he has collected independently. He rejects rightly the method of ocular estimate and the estimate by rule of thumb in which a fall in quarter girth is allowed for every 10 feet or so in length above breast height, although he is possibly a little unfair to the latter method which works well enough in the hands of a man who knows what he is doing. Instead, he has prepared a set of taper tables based on Behre's form class 70 (he defines 'taper' as the relation between basal area at 5 feet and the sectional area at mid-length), and the set of tables covers the common conifers about which we have a certain amount of information, but does not refer to hardwoods, for which the author gives a separate preliminary table based on what little information he has been able to bring together.

With the tables for height and for taper in his hands, the valuer can proceed with his volume determination on the assumption that his trees are of the average form and class. When he has reason to believe that the taper exceeds or falls short of the measure, certain adjustments are necessarily required and these introduce certain disturbing elements. In dealing with a method of this kind a reviewer naturally tends to look for points which he can criticize or which offend against his own ideas. There are many such points in this publication, but there seems to be no object in emphasizing them. The question we must ask is this: 'Does it work?'

This can only be settled by tests much more severe than those to which the author has hitherto subjected his method.

I said earlier that Mr. Davey went straight to the heart of the matter, but after reading his book through I think this is not quite true. The arrangement in the material in his book leaves a good deal to be desired and makes reading difficult. This is partly a consequence of the author's enthusiasm, but it does not help those readers whose patience has shortened as their years have increased.

The English Woodland. By JOHN ROGERS. xii+132 pp. 96 illustrations. B. T. Batsford, Ltd. 10*s.* 6*d.* net.

Review by W. L. TAYLOR

THROUGH the ancient by-ways of woodland folk-lore and legend, and with a brief review of our forest history of the past, the author leads his readers on a most interesting pilgrimage through the woods and forests of England, the names and memories of which have survived the destructive inroads of both man and the elements, and the neglect of public indifference throughout historic times. It is sad but true that of so many of our former forests little but a memory now remains. The book is a brave attempt to call to mind the English country-side as it has been and now is. It touches upon the present-day importance of forests and forestry in rural economics, and, by inference, upon the vital need for an enlightened and vigorous forest policy. The two great wars with Germany have brought out in terms that no one can mistake the perils besetting a forestless island in modern warfare, and the urgency, in defence, of adequate home-grown supplies of the right kinds of timber. In his pleasingly written chapters, enriched as they are by many quotations from other writers who have succeeded in capturing the spirit of this 'green and pleasant' land, the author presents a work that can hardly fail to influence a public that is not yet, in any great degree, forest-minded.

More such enjoyable literature telling of forests and the benefits they bestow, and calculated to induce forest-consciousness in the people of Britain, is badly wanted. It is to be hoped that Mr. John Rogers's book will be widely read and that many appetites may be whetted for a broader knowledge of forestry. The nation's need for conifers is wisely pointed out, and readers will glean that forests of trees never remain static; seed-time and harvest must follow one another in forestry as in all other forms of land cultivation if gross waste is to be avoided. There are far too many old and decrepit trees, long past their prime, standing in the English woods of to-day which are so full of the defects of age as to be entirely useless for conversion into timber for use in the life-and-death struggle in which the British nation is now engaged, and timber is an essential munition of war. The illustration of a derelict oak wood (opposite p. 120) is a portent of what follows the non-observance of the elements of systematic forestry.

The author ends on a clear note. 'For spiritual and mental health we need woodland. In a country where we cannot have great vistas and which specializes in little intimate scenes, and, moreover, is grossly over-populated, trees are a necessity.' This passage would be even more true if forests had been written instead of trees. There is still ample room for adequately extensive forests in parts of Great Britain. The ninety-six illustrations, many of them very beautiful, are of the standard to be expected of the House of Batsford, but it is not an unfair criticism that they depict, in the main, trees and glades rather than forest subjects. British public opinion has confused arboriculture with forestry ever since the days of John Evelyn.

Forest Tree Seed. By HENRY IVES BALDWIN. New Series of Plant Science Books, Volume VIII. Waltham, Mass., the Chronica Botanica Co., Wm. Dawson & Sons, Ltd., London, W. 1. 1942. Price $4.75.

Review by H. M. STEVEN

A LARGE number of papers on tree seed has been published during the past twenty years. These are scattered in many journals, not all forestry, and are in several languages, hence it is useful alike to the practical man and the specialist to have the results of these investigations brought together in one volume.

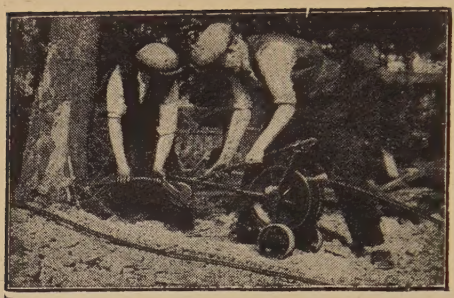
The increasing complexity of the science of forestry is shown by the issue of a book on a subject such as tree seed, and as stated by the author only a selection of the material available could be included. Dr. Baldwin has, however, dealt comprehensively, if in some respects not intensively, with the subject. The scope of the book is best shown by the subjects of different chapters: structure and development of tree seeds; seed production of forest trees; seed origin or provenance; seed collection; extraction and cleaning of seed; storage and longevity; biotic enemies of tree seeds; germination; internal factors affecting germination; environmental factors influencing germination; chemistry of seeds and germination; seed stimulation; seed testing; purity analysis; determination of origin; determination of seed viability without germination; the testing of germination; seed testing stations and germination; and tree seed research.

The book is a compilation, and much of the work on which it is based is uneven in quality and contradictory in results, hence the task of the author was one of difficulty, particularly on the subjects dealing with experimental results. The practical man would probably have preferred more categorical statements, but these are not yet possible in many instances.

The first two chapters on structure and development and seed production contain much interesting material some of which will be new to most readers. The author has avoided the temptation to digress into botanical by-ways. In some respects the chapter on provenance is disappointing. Perhaps the richness of the material and limitations of space are the reasons, but a genetical approach to the subject would have been more stimulating, and the importance and interest of the subject justified a fuller discussion, because we still lack that in English. The next few chapters on seed collection and storage contain information of practical importance. The chapter on biotic enemies stresses the importance of a subject often overlooked; a certain amount of work done in this country on *Megastigmus* spp. is not referred to. It would appear that the discussion on internal and environmental factors affecting germination should have preceded that on germination. These three chapters are good summaries of the subject, but work done in this country has been overlooked. Seed stimulation is a subject on which much work has been done, generally with negative results, and little space is rightly given to it. The chapters on seed testing, &c., follow orthodox lines, but reference is made to Schmidt's interesting phototropic method of pine race determination, and the newer methods of determining viability such as Merl's diaphanoscope, and catalase activity, &c., are described. The chapter on tree seed research does not contain anything of special interest.

The literature is referenced at the end of each chapter; there are subject and author indexes; while the book opens with an apt quotation from Shelley.

The author and the publisher are to be congratulated on the issue of this interesting and useful volume. It will be of considerable value to foresters in this country in view of the large programme of afforestation which will be called for after the war.



MONKEY WINCH

Tree and Stump Puller

Stub felling trees becomes a different proposition altogether with this machine. The same men, but only a small fraction of the time, and all the roots come out with the tree. Invaluable for getting dangerous trees, and those overhanging roads and buildings.

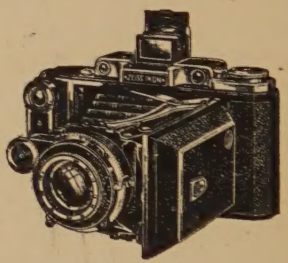
The procedure is to anchor the winch as shown above. The power is applied by moving a steel lever, and a stout steel cable transmits the pull (anything up to 24 tons) to the tree being pulled. A practical machine. Used on the royal estates both at Windsor and Balmoral.

Write for Illustrated Catalogue

TREWHELLA BROS.,
Pty., Ltd.,
ROLFE STREET, SMETHWICK
BIRMINGHAM

CAMERAS

Complete Stocks of all the latest Cameras by the leading Manufacturers



We specialise in the correct PROCESSING OF FILMS *and the making of* PRINTS, ENLARGEMENTS, *and* LANTERN SLIDES

J. B. WATSON

3 Frederick St. EDINBURGH **13 and 15 Shandwick Pl.**

THOMSON'S HOTEL
26/27 Drumsheugh Gardens, EDINBURGH
'Phone 22395
Position central yet quiet Elevator and all up-to-date equipment
Excellent cuisine—reasonable rates

SOME OXFORD BOOKS ON
FORESTRY

EXOTIC FOREST TREES IN THE BRITISH EMPIRE
By R. S. TROUP
Pp. 268, with 4 folding maps. 20*s.* net

SILVICULTURAL SYSTEMS
By R. S. TROUP
Pp. 212, with 86 illustrations. 21*s.* net

THE ECONOMICS OF FORESTRY
By W. E. HILEY
Pp. 270, 18 diagrams and graphs, 58 tables. 21*s.* net

TIMBERS
Their Structure and Identification
By W. S. JONES
Pp. 160, with 165 illustrations. 15*s.* net

FORESTRY FOR WOODMEN
By C. O. HANSON
Pp. 240, with 28 illustrations. 6*s.* 6*d.* net

OXFORD UNIVERSITY PRESS

CONTENTS

Some Ecological Aspects of Afforestation and Forestry in Great Britain (with Plates I–IX). By SIR ROY ROBINSON 1

Investigation on the Rate of Drying of Pit-props. By W. H. GUILLEBAUD . 13

Anisotropic Contraction of Wood and of its Constituent Cells. By R. D. PRESTON 32

The Variability in Resistance to Decay of the Heartwood of Home-grown European Larch, *Larix decidua*, Mill. (*L. europaea*) and its Relation to Position in the Log. By K. ST. G. CARTWRIGHT 49

The Number of Sample Trees required for determining Volumes of Woods with Various Degrees of Accuracy. By REGINALD DAVEY . . . 52

Society's and Other News 56

REVIEWS

Measurement of Trees (REGINALD DAVEY). By JAMES MACDONALD . . 56

The English Woodland (JOHN ROGERS). By W. L. TAYLOR . . . 58

Forest Tree Seed (HENRY IVES BALDWIN). By H. M. STEVEN . . . 59

Printed in Great Britain at the University Press, Oxford, by John Johnson, Printer to the University